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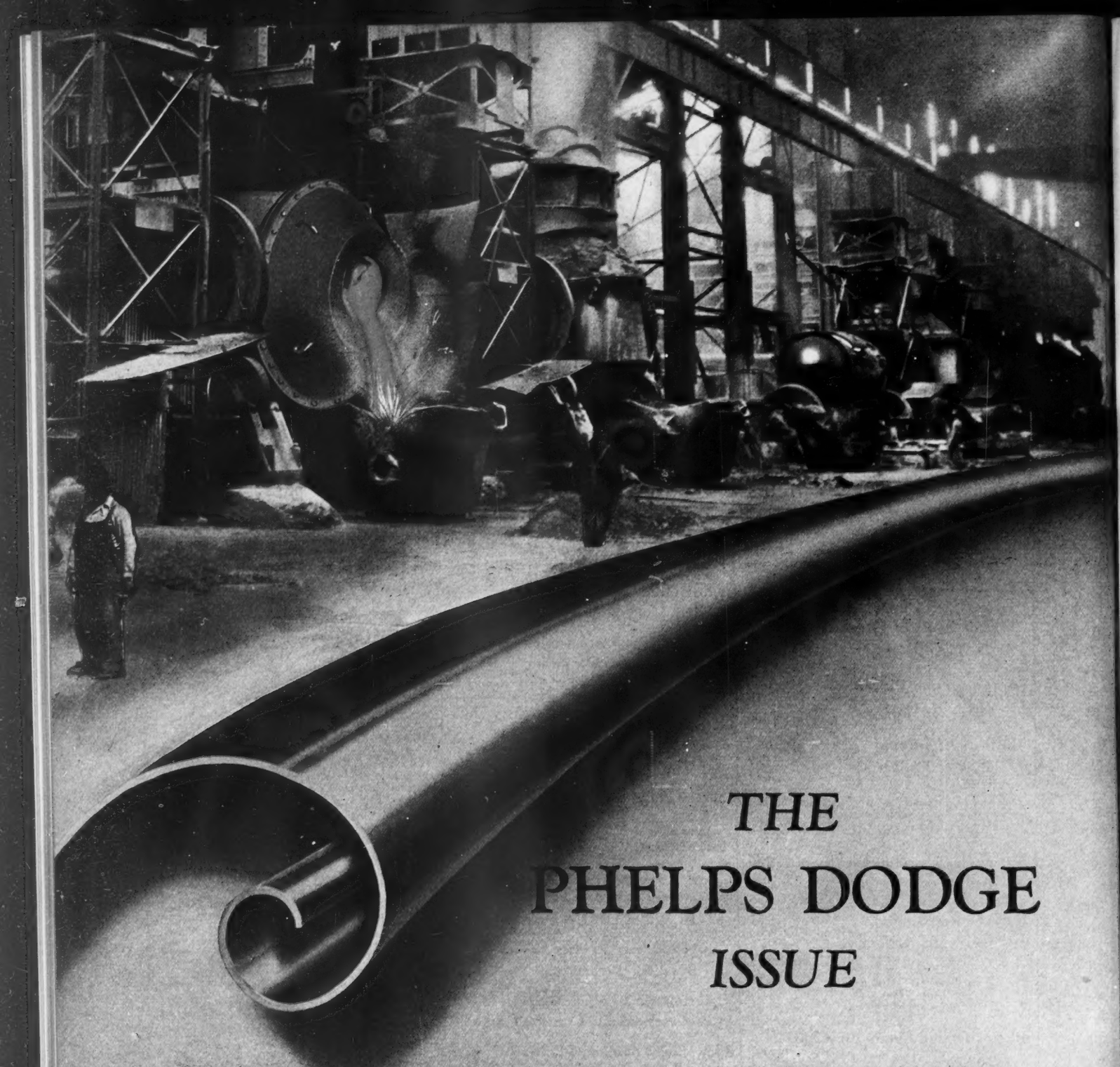

THE PHELPS DODGE ISSUE

A REFERENCE BOOK of facts, dealing with the complex operations of one of the leading and most progressive companies in the mining industry. Something to study—something to think about!

Why Phelps Dodge has attained an enviable eminence in the world of mining. How it has been done, *and with what* . . .

No mining man, from the Yukon to the Witwatersrand, heretofore denied this opportunity for enlightenment and inspiration, hasn't yearned for it. At last . . . the Phelps Dodge issue . . . here it is!

Progress in mineral recovery, ore dressing and metal marketing has been rapid and world-wide, largely because mining men and mining companies, like a chain of hands around the world, have reached out to help each other. No technical field in industry has profited more from a generous and broad-visioned interchange of opinion and operating experience.

And yet, so isolated and scattered are mines and metallurgical plants, so impracticable are personal contacts and inspection trips, that mining men have usually to wait for years to get inspiration of collective benefit from the great and progressive properties that are leading the march toward the goal of efficient and economical direction and operation.

Such was the thinking that brought you this issue. Unique in all the 62 years of international service initiated by *Engineering and Mining Journal*, it will be the first of a series of similar "pilgrimages," if adequately received and approved by you, the reader.

For the breadth of vision and wholehearted cooperation that has made this initial effort possible of achievement, we extend grateful appreciation and warm wishes for continued progress and prestige to the entire Phelps Dodge organization, also to the engineers and manufacturers whose equipment helps to turn the busy wheels of progress on the many properties of one of the outstanding mining enterprises of the world.

—THE PUBLISHERS

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MINING JOURNAL

McGraw-Hill Publishing Co., Inc. JAMES H. MCGRAW, *President*

A. W. ALLEN, *Editor*

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THE SPIRIT OF A GREAT ENTERPRISE

SUCCESS, in terms of achievement, may be the purely materialistic variety that must buy friends, or that type into the very fabric of which is interwoven evidence of an influence that makes for individual and industrial initiative and loyalty of the highest order. The record of the Phelps Dodge Corporation is in the latter class, and it is therefore an especial privilege for *Engineering and Mining Journal* to be permitted to devote an entire issue to the details of operation of this great enterprise. The evidence, in all branches of the Corporation's activities, of that high plane of endeavor which characterizes the recent history of one of the most important group-mining enterprises in the world indicates a traditional adherence to the philosophy of life of James Douglas (1837-1918), founder of its greatness, to whom the mining industry at large owes tribute for his insistence on publicity in technical matters, and for blazing the trail in the direction of happier relations between employer and employee. Recognizing no handicap in an education that to others might seem inadequate as a foundation for work in the field of geology, mining, and metallurgy, Doctor Douglas, by reason of a generous nature and a deep but not a specialized learning, attained the highest eminence in our profession—as engineer, industrial pioneer, administrator, humanitarian, philosopher, philanthropist, and writer—leaving behind him an example to inspire a wider growth of technical and economic improvement in the mining industry. The success of Doctor Douglas may be attributed in large part to a personal magnetism that attracted and held capable men for executive and operating positions. Giving of his best to others brought commensurate returns; and the turn of the tide in the status of the Copper Queen property owing to his wisdom and foresight and courage, after the first orebody was exhausted in 1884, brought a broader generosity to an already kindly personality. The spirit which he fostered and left with the mining industry is reflected in the group memorial at Nacozari, Mexico—a reproduction of the Fontaine Blondat at Dijon, France—chosen as the basis for the cover design of this issue.

> "The motives influencing the great body of writers . . . to give to the brethren of their craft the results of their own often dearly earned experience are various and complicated. But, in the majority of cases, the impulse originates in the desire for reciprocity, and in the hope that others will tell what they know, in return for what we ourselves communicate, and that therefore we shall learn at least as much as we can teach."—*From the Presidential address of Dr. James Douglas before the A.I.M.E., 1899.*

To quote a tribute from one of many appreciations published in the *Mining and Scientific Press:* "A man who has touched the hearts of youth with the flame that kindles to high endeavor, who has created ideals for a fraternity upon whose skill and industry the nation depends so largely for defense in war and for progress in times of peace, is one whose name will live and be known with increasing honor as time clarifies in sharper outline the greatness of his work."

Si monumentum requiris, circumspice.

A. W. Allen

Historical Sketch

By Walter Douglas

President

WHAT today is known as the Phelps Dodge Corporation is a product of evolution, its genesis going back 115 years to the incorporation of the metal-importing firm of Phelps & Peck. In 1834, following and perhaps due to the collapse of a new warehouse erected on the corner of Fulton and Cliff Sts., in which several lives were lost, Anson G. Phelps reorganized the firm, taking in as partners his sons-in-law, William E. Dodge and Daniel James. The principal business of the firm at that time was the exportation of cotton to England and the importation of tin and other metals, necessitating a representation in Liverpool, so that the new partnership consisted of the American firm of Phelps Dodge & Company, and its English branch, Phelps, James & Company, of which Mr. Daniel James directed its destinies for a period of 48 years.

The importance of this firm in the trade of the country at that time can be measured by the volume of its transactions, which increased from the time of its organization from 100,000 boxes of tin plate to 14 million in 1874, or 30 per cent of the domestic consumption. In 1890, one-seventh of the world's production of pig tin passed through the books of this firm.

In addition to the metal business, large purchases of timber land in Pennsylvania were made and the manufacture of lumber was engaged in. This enterprise started with local sawmills, but the expense of transporting large amounts of lumber led eventually to the abandonment of small mills upstream and the erection in 1849 of a large sawmill on the Jersey shore of the Delaware River known as the Phelps Mill. Still later, in 1864, at Williamsport, there was built one of the largest mills at that time east of the Alleghenies, which was given the name of the Dodge Mill. This extensive lumber business was for many years conducted under the firm name of Henry James & Company, of Baltimore, to which point most of the lumber was shipped.

As a factor in the copper industry Phelps Dodge & Company came into national prominence through supplying the wire for the first telegraph line between New York and San Francisco, it having been manufactured at Warrington, near Liverpool. The firm had before this established a rolling mill at Derby, Conn., on the Naugatuck River, and a little further up the stream it built a village which was named Ansonia, after Anson G. Phelps. The operations grew into independent corporations, including the Ansonia Brass & Copper Company and the Ansonia Clock Company, and to these works came copper from the West for fabrication.

The firm's interest in the purchase and sale of copper brought it into touch in 1881 with James Douglas, who interested the then senior partners, William E. Dodge and D. Willis James, for the first time in the actual mining of copper. Thus nearly 50 years ago was initiated the era of productive development of the mineral deposits of the Southwest and, contemporaneously, the construction of a great transportation system which eventually linked the mining camps with transcontinental carriers. Dr. Douglas was at that time operating a copper refinery known as the Chemical Copper Company, at Phoenixville, Pa., and in order to obtain crude copper and mattes for his plant he had visited the mining districts of Chile and the copper camps of the Rocky Mountain States.

Telling of his first connection with Phelps Dodge & Company, in an article published in 1899, he says:

"It was during the winter of 1881 that I was first introduced to the members of the firm of Phelps Dodge & Company. Mr. Dodge asked my advice as to whether the smelting works could be advantageously erected on an island in Long Island Sound, bought by his father long before for that purpose. I had no hesitation in assuring Mr. Dodge that building smelting works of the old type would be wasting money, as the Revere and Baltimore works were idle through the falling off of mining in the Allegheny Range, and as all western ores would ultimately be smelted at the mines.

"I pointed out that these western ores carried gold and silver, that the cost of separation in the West was prohibitory and that I believed that refining and separating works on the coast would be highly remunerative. I had made some tons of electrolytic copper in Phoenixville, under the guidance of Edward Weston. This was the first electrolytic copper marketed in this country, and I was convinced that this method would supplant all others, and that the first in the field would reap the harvest.

"During the conversation Mr. Dodge said that a handsome, attractively frank man had that morning entered the office and without any introduction asked for $50,000 with which to build copper works near Longfellow, Arizona. The extraordinary effrontery of such a demand by a perfect stranger would have been resented but for the genuine sincerity and absence of all bluster or exaggeration on the part of the applicant. He was a Mr. William Church. He had secured undivided control of a number of claims near Clifton, adjacent to the Longfellow, by getting options on all the stock of the Detroit Copper Mining Company. He wanted the money to develop his mines and erect smelting works. As Ansonia was treating Copper Queen copper, the subject interested Phelps Dodge & Company, and Mr. Church had not been summarily dismissed.

"I told Mr. Dodge what I knew from personal observation of the Queen and what I knew from reliable information of the Longfellow. My story so impressed him that he employed me to make a report on Church's property as the information would be of value to them, even though they did not accede to Mr. Church's request. Thus Church and I were strangely mingled during our first introduction to Cliff Street, and the members of the firm of Phelps Dodge & Company took their first plunge into copper mining."

The prospects adjoining the Longfellow, to which Dr. Douglas referred, became the mines of the Detroit Copper Mining Company, in which Phelps Dodge & Company, through its financing of Mr. Church, obtained only a minority interest. It was not until 1897 that, through Dr. Douglas' advice, the Church and other outstanding interests

were purchased, and in 1921 the old Longfellow mine referred to and operated for so many years by the Arizona Copper Company, Ltd., an Edinburgh corporation, was acquired through an exchange of stock.

Next to the Copper Queen mine at Bisbee was a claim known as the "Atlanta," which was acquired in 1881. Development of this claim, so discouraging in its early phases, resulted in the finding of rich ore, which proved to be an extension of the Copper Queen main orebody and eventually brought about the amalgamation of the two properties.

Subsequently other mines at Bisbee were acquired, including the Holbrook & Cave, Neptune, and Copper Prince, and in 1885 the Copper Queen Consolidated Mining Company was formed. The acquisition of further properties in the Bisbee District has continued as development operations warranted further purchases.

In the early days of the camp, and at the request of the miners, the management agreed to open a small store to supply the community, at a small profit, with the necessaries of life. This enterprise, established on the principle of the purchase of goods in volume and in the most favorable markets, has grown into a mercantile company with twelve stores in Mexico, Arizona, and New Mexico, with sales of more than five million dollars annually.

In the late 'eighties Mr. William E. Dodge visited Arizona to observe the mining operations in which he was interested. He met the Hon. C. C. Bean, then delegate to Congress, and was induced to visit the Copper Basin property owned by the latter, in Yavapai County. This undeveloped prospect, a copper carbonate impregnation of conglomerates, was very striking for the brilliancy of its coloring, extending over a large area.

Mr. Dodge was greatly impressed by this property, and it was acquired, together with the Senator, a gold mine on the Hassayampa, and the Boggs & Hackberry mines, about 20 miles east of Prescott. These three properties were incorporated as the Commercial Mining Company, this title being chosen by Mr. Dodge because, as he said, the name suggested stability and success. A leaching plant, smelter, and gold mill were erected, and development was actively conducted. Unfortunately, the orebodies were uncertain in extent and the enterprise proved to be a financial failure.

In 1897, the property of the Moctezuma Copper Company at Pilares de Nacozari, in Sonora, Mexico, then owned by the Guggenheim interests, was brought to Dr. Douglas' attention, and after a thorough examination was purchased. While the grade of the ore was too low and the cost of transportation too great to permit of profitable operations with the old smelting plant at Nacozari, the construction of a railway 75 miles in length from the frontier to Nacozari de Garcia, where a mill and smelter was erected, made this enterprise a profitable undertaking, and the mine has been a large producer.

In 1909, the stock control of the Burro Mountain Copper Company, owning claims near Silver City, N. M., was acquired and development work carried out, which appeared to indicate the existence of important low-grade bodies of partly oxidized sulphide ores. A year or two later the adjoining properties of the Chemung Copper Company and the Savannah Copper Company were bought, modern mining plants were installed, and a concentrator was built.

Productive operations continued throughout the period of the war; but, with the drop in the price of copper and the necessity for a restriction of production, the branch was closed down in 1922. Operations have been confined since then to mine development and exhaustive experimentation on the susceptibility of the ores to leaching, with satisfactory results.

Tombstone, Ariz., so famous in early Western history as a bonanza silver camp, had gradually sunk in importance as a producer until its output had become negligible. A consolidation of the old mining companies in 1907 was perfected, and an attempt made to reach depth, to determine if profitable ore could be found below the surface anticlines which had formerly been so productive. Unfortunately, the flow of water was so great that the capital subscribed was insufficient to accomplish the object.

In 1914, the Tombstone Consolidated Mines Company being bankrupt, the Phelps Dodge Corporation (through its predecessor, Phelps Dodge & Company) acquired the properties at Trustee's sale, and its subsidiary, the Bunker Hill Mines Company, has since operated the mines at a small profit, but has been unsuccessful in finding any large high-grade deposits similar to the original discoveries which made the camp so famous.

In 1917, the then operating companies—namely, Copper Queen Consolidated Mining Company, Detroit Copper Mining Company, Burro Mountain Copper Company, and Stag Canon Fuel Company—were merged into a company incorporated as the Phelps Dodge Corporation, with a capital of 500,000 shares of $100 par value, which latter corporation also acquired the capital stocks of the Moctezuma Copper Company, Bunker Hill Mines Company, and Phelps Dodge Mercantile Company. Whatever success—and it has been considerable—that attended the development of these large mining interests has been due entirely to the foresight of the directing spirits in pushing the facilities of transportation forward, contemporaneously with the development of the mines.

With the commencement of smelting operations in Bisbee, the problem of transporting coke and supplies into the camp and copper bullion to the railway by mule teams became more difficult as production increased. As neither of the great railway systems in the Southwest was inclined to extend its rails to a mining camp of problematical future, it became necessary to construct a line of railway from Bisbee to a connection with the Santa Fé's New Mexico & Arizona Railway at Fairbanks. This railroad, the Arizona & Southeastern, which was 37 miles long, was completed in 1886.

During the receivership of the Santa Fé in the 'nineties, a heavy increase of freight rates ensued, and it became necessary to extend the Arizona & Southeastern to a connection with the Southern Pacific at Benson, which was accomplished in 1897.

With the acquisition of the mines of the Moctezuma Copper Company, and because of the restricted area for extension of smelting facilities in the Bisbee camp, it was decided to construct smelting works at some point adjacent to the Mexican frontier, where the product of both the Copper Queen and Pilares mines could be treated. After careful investigation a suitable location in the Sulphur Springs Valley, immediately north of Nacozari and southeast from Bisbee, distant about 25 miles, was chosen, and in 1900 the construction of a new and modern reduction works was commenced at that point, which now adjoins the city of Douglas.

To transport the ores and concentrates economically the El Paso & Southwestern Railroad Company and the Nacozari Railroad Company were organized, the latter comprising the railroad from Nacozari to Douglas, and the former, on the purchase of the Arizona & Southeastern, extending its tracks into the Sulphur Springs Valley and thence easterly paralleling the Mexican frontier to Deming, N. M., and El Paso, Tex. Here direct connection was made with both the Santa Fé and the Southern Pacific, with a material shortening of the haul.

The necessity of obtaining for the Southwestern smelters a regular and adequate supply of coal and coke dictated in 1903 the acquisition of the El Paso & Northwestern Railway, whose western terminus was El Paso, and which tapped the rich coal fields of the Trinidad seam on the Maxwell land grant at Dawson, in the northeastern corner of New Mexico. These coal mines were acquired and extensive coke ovens constructed, which, until the substitution of the reverberatory process for blast furnaces, furnished most of the coke necessary for smelting operations conducted in Arizona and northern Mexico.

A later development of the railroad system was the extension of the line to Tucson, Ariz., with the eventual intention of building through to the Pacific Coast. In 1923, however, it was deemed desirable to consolidate the El Paso & Southwestern System with the Southern Pacific Company and this was accomplished in 1924, the mileage then having increased from the original 37 to over 1,300.

A Flow Sheet of Organization

By P. G. Beckett
General Manager

DICTIONARIES tell us that the definition of the word organization is "A number of individuals systematically united"; and, similarly, that to organize means "To bring into systematic relation as parts of a whole," or "To become systematized into a whole of inter-dependent parts," which with special reference to the flow sheet of organization of an industrial concern is probably the more technically correct way of saying that good organization is "The systematic arrangement of the work of a body of men so as to achieve the maximum results with the greatest simplicity, efficiency, economy, and smoothness."

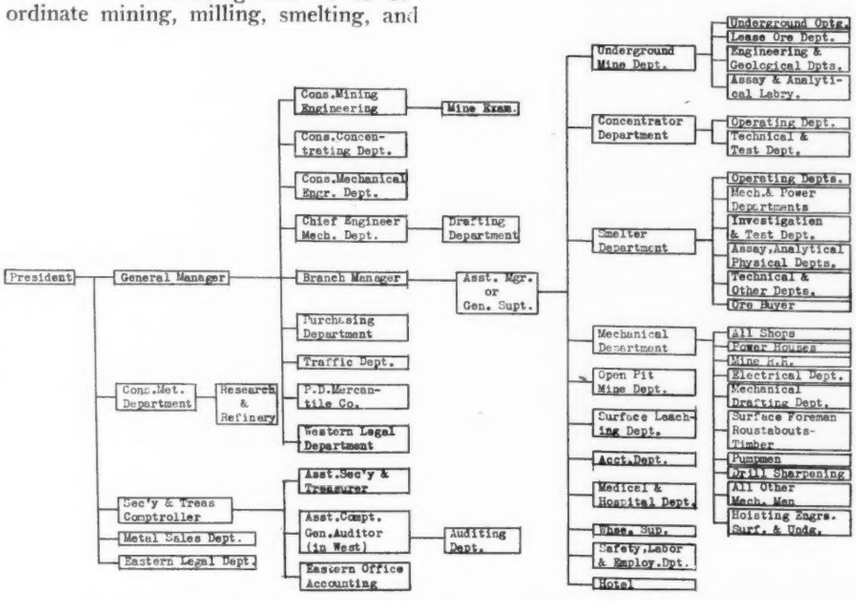
Although varying conditions must be governing factors in the details of any flow sheet of organization adopted, certain correct fundamental principles are essential, regardless of conditions, location, or of the size of the operation. With the principles basically correct, a flow sheet of organization can be expanded or contracted at will, and can be made to function satisfactorily for a property with a large number of men or a small number of men, irrespective of geographical location and other conditions.

It is self-evident that a single small property with a compact, concentrated operation and with a comparatively small number of men requires a much simpler type of organization than does a large company operating several scattered units. In either circumstance, however, the basic principles of organization can be the same.

The Phelps Dodge Corporation owns properties in Arizona, New Mexico, and Mexico. It mines and concentrates copper and lead ores and mines coal. It smelts copper and lead ores and concentrates. Its properties are situated as follows: Mines at Bisbee, Tombstone, Yavapai County, and Morenci, Ariz.; Tyrone, N. M.; Nacozari and Pilares, Sonora, Mexico; smelters at Douglas and Clifton, Ariz., smelting custom as well as company ores; and coal mines at Dawson, N. M. An associated company is the Old Dominion Company, with mines at Globe, Ariz. Phelps Dodge Corporation also operates mercantile establishments at Bisbee, Lowell, Warren, Naco, Douglas, Morenci, and Clifton, Ariz.; at Tyrone and Dawson, N. M., and at Nacozari and Pilares, Mexico.

In order to obtain co-ordination in all phases of the operations in these scattered units, as well as in matters of policy, a general manager has headquarters in the West, reporting direct to the president of the Corporation in the East. All matters pertaining to Western operations are handled through the general manager. He in turn deals directly with his branch managers, who have full jurisdiction over their respective properties. Besides the branch managers, the general manager has directly under him the members of his technical consulting staff, the general manager of the Mercantile Company, the manager of the Traffic Department, the manager of the Purchasing Department, and the Western Legal Department. The function of the members of the consulting staff is to co-ordinate mining, milling, smelting, and mechanical matters; to assist in standardizing equipment and methods at the different operating branches; to see that the best general use is made of results obtained at any one branch and to avoid mistakes made at one branch being duplicated at another; to make special studies and analyses of the different phases of the operations; and, having greater opportunity for visiting outside plants, to keep the branches up to date on the latest progress in mining, milling, smelting, and power. In brief, the function of the consulting staff, although having no direct authority over their departments at the different branches, is to give service to the general manager, branch managers, and superintendents.

In the chart of organization accompanying this article, the flow sheet indicated under the branch manager is the one used by the Copper Queen Branch, which is our largest and most complicated branch organization. The mines and concentrators are in the Warren district and employ about 1,500 men. The smelters, for copper and lead, are at Douglas, 25 miles distant, where about 800 men are employed. As an index of the complexity of this particular unit, it may be mentioned that operating sections of the mine are as far as three miles apart and that seven different types of copper-ore products are shipped from the mines and concentrator.



Directly under the branch manager is usually an assistant manager or general superintendent, who relieves the manager of much detail and routine, which permits the latter to keep out on the job and give his time to the more important matters. Under them come non-operating or service departments, such as Accounting, Warehouse, Medical and Hospital, Safety, Labor and Employment. Parallel with these non-operating departments are the main operating departments, heads of which report directly to the branch manager and his assistant. At the Copper Queen Branch, the largest operating departments are the Underground Mine Department, Concentrating Department, Smelting Department, and Mechanical Department.

All mechanical men and shops on the surface and underground, carpenter shops and crews, surface roustabout gangs, and power houses are under the supervision of the master mechanic. In a large organization, this leads to better co-ordination than having too many individual foremen reporting direct to the management.

The smelter, being situated at some distance from the mine, is, as the chart shows, a more or less self-contained unit, grouped under and reporting to the smelter superintendent. No regular construction department is maintained, but routine construction work is handled by the Mechanical Department. Major or special construction work is taken care of either by the Mechanical Department or by an outside contracting concern. Major designing is handled by the Phelps Dodge Corporation mechanical engineering office or, in special instances, by an outside engineer. Minor designing is taken care of by the branch mechanical department draftsmen.

In the Phelps Dodge organization, the separate units of organization under the branch manager, whether major or minor, are termed "Departments." The more correct and distinct nomenclature would be "Division" for a main department covering underground mining and smelting, with "Departments" grouped under them.

Such is a rough outline of the flow sheet of a scattered and necessarily complicated operation. The other extreme is our Tombstone operation, which, in the handling of leasing operations, has a superintendent, who also keeps all books and records of shipment; one mechanical man to run the power house and machine shop; one general-utility man for handling supplies and hoisting ore at the different shafts, and one night watchman; or four men in all. The scale of the operation and other governing conditions are, therefore, what control.

A few of the major organization principles that have been aimed at are as follows: To make the flow sheet of organization as simple as possible. To see that every man shall have only one boss and shall know exactly who that boss is; in other words, straight-line organization and the avoidance of short-circuiting of authority. To tie in, in an organization of any size, gangs and minor departments under major department heads, and to avoid too many unco-ordinated small departments reporting direct to the manager. Neglect of this principle is bound to result in confusion and waste of the manager's time.

Perhaps it is unnecessary to add that, in any organization, the choice of the right man in the right place is probably the most important principle of all. Just as the strength of a chain is equal only to its weakest link, so in an industrial organization the wrong choice for a major position not only is the cause, in turn, of wrong choices for his subordinates, but tends to disorganization, disruption, and lack of co-ordination within his own department and with parallel departments in the organization, thereby impairing the effectiveness of the whole.

However difficult of achievement, it should be the aim of every manager, superintendent, department head or foreman never to be satisfied with anything ill-fitting in the way of personnel, or ill-defined in the way of organization procedure. For if work, regardless of its size, is well and properly organized, it becomes a source of satisfaction to all taking part in it—workmen, bosses, and management.

Appropriation Procedure

By J. H. Davis
General Manager's Office

ALL branches of Phelps Dodge Corporation make application in the form of an appropriation request for certain expenditures outside of the usual operating expenses. These appropriations are prepared by the individual branch management and are submitted to the general manager of the Corporation for his approval and through him for the approval of the Executive Committee in New York.

Formal application for an appropriation is required for the following classes of expenditure when the estimated cost is $2,500 or over: (1) Purchases of mining claims, real estate, houses and other property; (2) new construction or additions to plant facilities, including, besides direct-operating units, such items as houses for employees and educational and recreational projects; (3) betterments of property—new equipment or plant replacing existing equipment or plant, with the object of increasing capacity or efficiency; (4) extraordinary expenditures that cover expenditures for special investigations beyond the routine work of the investigation department of the branch, special mine examinations, and outside projects; (5) extraordinary mine development and exploration program. Formal applications for appropriations are likewise required in the case of repairs, renewals, and replacement of existing plant or equipment when the estimated cost is $5,000 or over.

The preparation of appropriation requests for the above-mentioned classes of expenditures serves many purposes, chief among which are the following: (1) To emphasize the aspect of "new money" being required, so that due consideration of the justification for the expenditure is challenged; (2) to insure that the general manager, president, and directors have the necessary knowledge of and give approval to all extraordinary expenditures; (3) to make sure of the preparation of accurate estimates of costs and plans, resulting in a clearer conception of the project to be undertaken, with attendant lower cost of construction; a careful estimate of the proposed work may show the futility of the project

and cause its abandonment without loss of money; (4) to serve as a standard to measure actual costs, thus bringing to notice errors in the original plans that can be avoided in similar work in the future; (5) to give the management a guide to follow throughout the construction period.

Each branch appropriation is numbered, the numbers for each subsequent appropriation following in sequence. An appropriation covering an over- or under-expenditure, or increasing the amount of the original appropriation, bears the number of the original appropriation with a suffix letter added. The appropriation contains estimates and plans, and an explanation of why the expenditure is necessary and the saving to be accomplished by the proposed installation.

In making up an appropriation request, the arrangement and detail of the estimated cost is shown in a manner in which it is desired the final costs be assembled. That is, the Accounting Department of the branch being consulted, the operators concerned determine what details or sub-accounts are needed, so that when the job is complete the record will give the most useful and accurate information. The estimate and final costs are thus compiled on the same principle, insuring comparable costs and furnishing the proper basis for relation between the estimated and actual figures. Job numbers are given each sub-account, and all charges are segregated directly thereto, the Accounting Department of the branch issuing a bulletin covering the cost outline for the guidance of all concerned in reporting the charges.

In regard to new construction, the appropriation states, with reasons outlined, the rate or period of time over which the construction should be depreciated. This applies also to betterments of equipment or plant. The appropriation also indicates whether the expenditure is chargeable to "Construction" or "Operating." Both as to depreciation rate and charges to either, the comptroller makes the final decision.

As soon as the job is completed and the final costs are compiled, if there is an under- or over-expenditure, formal application is made for an appropriation canceling the unexpended amount, or for an additional appropriation covering the over-expenditure. A full explanation of the reasons for either accompanies the request, together with a comparative statement showing the estimated and final costs, arranged so that the difference in costs of the various subdivisions is readily seen. If it becomes apparent as the work progresses that, prior to completion, the appropriation will be over-expended by an amount equal to 10 per cent or more of the original estimate, full advice in the matter is forwarded to the general manager, and his approval received before continuing the work.

In regard to major expenditures, a statement showing actual savings from new installations or replacements is compiled as soon as a sufficiently long period of operations has elapsed to permit the assembling of accurate data. An illustration of a typical appropriation request procedure is given herewith:

Typical Appropriation Request Procedure

PHELPS DODGE CORPORATION—

Appropriation No. —
————, 192—

Mr. ————
Vice-President and General Manager,
Douglas, Arizona.

Dear Sir:

Authority is asked for expenditure of ————Seven Thousand Two-hundred and Eighty————Dollars ($7,280.00), chargeable to Construction, for the following:

Erection of a 4,000-gallon capacity water softener to treat water for the boilers at the——smelter.

Depreciation rate———%.

Phelps Dodge Corporation——Branch,

————
Manager.

Approved

————
Executive Committee

————
Secretary

Granted

192—.

————
Vice-Pres. and Gen'l Manager.

Memorandum on ——— Branch Appropriation No. —. Erection of a 4,000 Gallon Capacity Water Softener to Treat Water for the Boilers at the ——— Smelter

This water softener installation will consist of necessary equipment to treat 2,000 to 4,000 gal. per hour of make-up water for the power plant steam requirements.

While 65 per cent of the boiler feed water is condensate from the turbine condensers, the remaining 35 per cent is raw water containing 10.3 grains per gallon of scale-forming constituents which is causing considerable expense for boiler cleaning and loss of boiler tubes, especially in our waste heat boilers on the reverberatory furnace.

The estimated cost of this installation is $7,280. The estimated cost of operating and treating supplies is 5c. per 1,000 gal. or, on present steam basis, about $75 to $90 per month.

It is difficult to make any exact estimate on the savings due to this installation, as a considerable proportion will be due to increased efficiency and longer periods of continuous operation on the boilers, but in addition to this the estimated savings on boiler cleaning and repair costs are $200 per month.

This installation has the approval of the Mechanical Department, Phelps Dodge Corporation, as per————letter of ———192—.

Estimate on 4,000-gallon Water Softener for ——— Power Plant

	Labor	Material	Total
Equipment from —— Co. as per proposal No. 622-A	.....	$1,860.00	$1,860.00
Freight on 12,000 lb.—N. Y	.....	560.00	560.00
Tanks made in——— 16,000 lb. material at 3.5c. per lb.	.....	560.00	560.00
Shop work	$480.00	.....	480.00
Assembling and riveting	240.00	.....	240.00
Erection of equipment	600.00	100.00	700.00
Excavation foundation and drain	75.00	.....	75.00
Foundation forms	150.00	100.00	250.00
Foundation concrete	250.00	250.00	500.00
Housing and lime storage	350.00	250.00	600.00
Pump and piping	200.00	200.00	400.00
Drain and sewer	50.00	25.00	75.00
Handling equipment for lime	50.00	25.00	75.00
Total	$2,445.00	$3,930.00	$6,375.00
Contingencies	.....	.....	905.00
Grand total			$7,280.00

Research Laboratory at Copper Queen Branch

Business of Mining

By Gerald Sherman

Consulting Engineer, Mining Department

PROGRESS for the past ten or fifteen years at the mines operated by Phelps Dodge Corporation has been found to follow the trend of advances in the art. New systems of stoping have been introduced and old systems improved. Standardization in methods and equipment has been adopted when desirable. The use of power and of labor-saving machines and tools has been greatly increased. General ventilation by large fans has been established in all mines, and there has been a distinct improvement in operating conditions and in safety. Contract or bonus systems have been introduced to replace, so far as practicable, the straight day's pay scale of wages.

By an interchange of information on methods and equipment found useful at one mine, duplication of investigation has been reduced, and improvements are more quickly adopted at others. The result has been a closer examination of mining practice by many observers, not only in regard to the efficiency of methods employed, but also as to their effect on the profit, which is the primary object in this highly competitive industry.

Four copper mines are working under the direction of Phelps Dodge Corporation—the Copper Queen at Bisbee, the Morenci branch mines at Morenci, and the Old Dominion in Globe, all in Arizona; and the mine at Pilares, in Sonora, Mexico, of the Moctezuma Copper Company. They are large enough, and have been in operation long enough, to have developed schemes of mining suited to their character. Such policies are based on the present and prospective size and character of the ore deposits, on the methods of reduction by which the copper is extracted, on the copper market, and on other factors that influence the program of production for the Corporation.

To secure the best results from a producing mine, it is necessary to control both the cost of operation and the value of metal content of the ore mined. It is difficult to say which is of greater importance, for they are interdependent. Operating costs will be considered first. The analysis of direct mining costs in Table I shows the relative importance of different processes.

The finding of ore and its development, and stoping, are the largest items on the list, and their combined cost and influence on policy control the profit. Their efficiency can be measured against recognized units even if, in comparison, allowances must be made for local conditions. The effectiveness of the search for ore should be judged by the cost per ton of the ore found, and not, as is customary, by the cost per foot of the work done for that purpose.

The remainder, generally service accounts, is split up into smaller natural divisions; and it is more difficult to measure the results, even if only because of the expense to collect data from a mass of details. They occasionally, therefore, receive less attention than their aggregate importance deserves.

Table I—Analysis of Direct Mining Costs

	Copper Queen				
	Limestone Mine	Porphyry Mine	Old Dominion	Moctezuma Copper Co.	Morenci Branch
Exploration and development, per cent	20	12	28	13	26
Stoping, per cent	35	29	26	51	29
Tramming, per cent	10	16	12	15	15
Hoisting, per cent	5	15	8	3	6
Total, per cent	70	72	74	82	76
Underground repairs, per cent	6	6	5	3	3
Drainage, per cent	9	4	8	1	1
Ventilation and sanitation, per cent	3	2	5	3	3
Sampling and assaying, per cent	1	3	1	1	2
Mine department expense, such as superintendent's department, foremen, engineers, per cent	11	13	7	10	15
	100	100	100	100	100

The rate of progress, in exploration and development, necessary to maintain ore reserves in proper relation to production, is dependent on the character of the deposit. In new deposits it is a matter of guess what the ratio should be. Knowledge is gradually gained, but toward the end of the productive life of a deposit there is another period of uncertainty.

In drifting and raising there are few variables, and practice has been standardized to a considerable extent. A study of the location of drill holes has developed a number of so called "standard rounds" for headings that differ in size or character of rock. They are not new in principle, but it is believed that they are founded on correct theory. It has been found generally profitable to teach new men to place their holes properly. Under most conditions this is done by instructors.

Well-designed rounds are of greater value in hard rock. Any kind of a round will break soft ground, but, even in the last-named type of formation, one that will clean it out neatly to the proper size, without shattering the surrounding rock, is worth more and requires less powder. This work is now generally done on contract or bonus. Wherever introduced, the effect of instruction, with the stimulus of extra pay for more progress, has been to increase performance, lower costs, and raise the earnings of the miner. At one mine, the average advance in drifting, per shift of labor employed, has increased 120 per cent in two years. Inasmuch as there has been less gain in mucking, the principal improvement has been in breaking ground.

In years gone by only two methods of stoping were used in these four mines, and nearly all the ore was mined by square setting. At present, six major systems are in use, with many variations. Inasmuch as ore deposits vary, different methods should be used to accommodate them. At the Old Dominion, great gains have been made by cutting loose from standard systems and in improvising variations to suit special conditions. This is theoretically and practically the correct method of approaching a stoping problem. A great fund of available information can be drawn upon in selecting a method, and, if necessary, experienced foremen can be transferred to assist in introducing it in another mine.

Two mines are equipped with efficient compound steam hoisting engines. At the others, electric hoists are used. Skips are used in hoisting ore, and generally for waste. Large cages, on which truckloads of steel or timbers can be run without reloading, are in use at two mines. Electric haulage is used at all mines, supplemented by hand

tramming. Storage-battery locomotives have been very successful when the power consumption per shift for each battery is not too great. The cost of repairs is largely a question of care in maintenance.

Stoping efficiency has been increased at Morenci by wider spacing of grizzlies, and by passing larger boulders through to the haulage cars and skips. Large chute doors are used, 42 in. wide; 60-in. doors are being tested. Cars and skips will be built to stand the shock. At least 30 per cent and generally 50 per cent of train time is spent in loading and unloading. The loading time is a function of the ore and chute door. Dumping depends on the cars and on a free discharge.

The cost of material such as timber, explosives, air drills, steel, and fuel for power constitutes a large part of the charge for mine supplies. Timber is saved by the selection of an economical stoping method and in the details of its operation. Small sections and close filling save timber in square setting, for example: Powder economy is founded on the correct location of drill holes, on the proper selection of powder, and on rationing powder by including it in the bonus or contract rates or by its issue under control of the foreman. Drills and steel are being standardized. The drill account is a heavy expense and hard to control in scattered operations. Compressed-air economy is obtained by maintaining tight air lines and by controlling its use for ventilation, not by the selection of drills.

Standardization is not a simple matter in mining. There must be freedom in the selection of methods to suit conditions. The method itself cannot be followed strictly; it must be guided in details by variations from the normal. Correct general principles, however, must be understood and practiced. Standard rounds in drifting or raising have increased the performance of less skilled men. They have not added much to that of the most competent 20 per cent of the miners employed. In large-scale mining operations, such as slicing and caving, their importance is great, because each individual operation is repeated thousands of times; but standardization should be approached by thorough study and trial, in which the best possible plan is developed, and that should be adopted as the standard. Standardization finds its best field in equipment and in shafts, cages, mine cars, drills, hoses, and tools in general. Among several mine organizations it is difficult to secure unanimous opinion on the equipment to be standardized. Standardization implies a compromise, and something must be sacrificed to attain it. Equipment must be selected after testing and not without full information.

Labor absorbs about 62 per cent of the direct expense of mining. Its effective administration is of corresponding value. Not long since it was customary to pay each man employed underground the same daily wage. At present, most of the work that can be easily measured is operated on a contract or bonus rate, in which the full wage is guaranteed; but exceptional performance is recognized by greater earnings per shift. Men are working on contract or bonus in the following proportions to the total employees underground: Copper Queen, 55 per cent; Old Dominion, 36 per cent; Moctezuma Copper, 88 per cent; Morenci Branch, 75 per cent. These systems are especially suitable in simple operations and uniform ground. When conditions change unexpectedly, the setting of contract rates is difficult, and though there is every intention to make them fair, complaints arise, sometimes unfounded, that are serious handicaps to any such plan.

Characteristic differences are noticeable in the administration of the two systems, but the same information is required for setting an equitable contract rate as is needed for a bonus standard. Having sufficient data, it is possible to make the average payments equal, per unit of work, in either scheme. The unusually efficient miner would receive more under contract than on bonus. Conversely, the man slightly below the average, if earning more than wages, would receive more on bonus. An unexpectedly large increase in performance has been usually noted when either of these systems is introduced, even in mines with a record for efficient labor. When work under contract or bonus is started, this must be recognized.

The proper selection of the ore to be mined has an influence on profits second only to that of the operating cost and occasionally equal to it. The method of stoping determines the cost of mining and the cleanness of the product. In estimating the effect of a cheaper method, with the possibility of producing slightly diluted ore, or the chance of losing some of it, the cost and recovery in subsequent reduction, and the price of copper, must be included. It is a sound principle that factors such as the cost of mining the ore and its treatment in every orebody should be known, and, in theory, of every set or even of every ton mined in a selective method, and the profit, if any, that can be derived from it. All stoping methods are selective, some on a large scale, as in caving, and some on a small scale, as in the irregular deposits usually mined by square setting.

At the Copper Queen mine, where the ground and ore occurrence are most erratic, the cost of stoping varies greatly in different stopes, and the cost of direct smelting is equally variable, depending on the composition of the ore. In addition, there is a range in value of precious metals contained, from nothing to several dollars per ton. All factors must be included in determining the quantity of copper it must contain to break even, and upon that quantity must be based the selection of ore in that stope.

The ore from this mine must be smelted, and comparatively heavy charges are involved for transportation to the smelter and the extraction of the copper. For this reason, and because the ore itself is irregular in value and occurrence, the control of grade is most necessary and most difficult. Under these conditions stoping practice should approximate the close supervision and personal interest that is typical of operations in a small mine or lease, worked by the owner or lessee.

Advance information on the characteristics of an orebody must be obtained by exploring and sampling, to show if a less selective stoping system is permissible. It must be proved whether or not sorting out included waste is profitable, but in most operations of the kind under consideration external ore outlines can be followed as they are developed in stoping. These conditions are illustrated at Pilares. Records indicate a gain there of four pounds of copper per ton by special, over ordinary, care in following ore boundaries carefully in breaking ore, and in intelligent sorting. It represents an increase in profits of about 25c. per ton of ore. To make a corresponding gain by reductions in mining and concentrating costs would be very difficult.

An ore deposit mined by caving is a step farther in the same direction. The value of the ore, and surrounding waste, and the ore outline must be known beforehand more accurately and completely than in a system that can adjust itself to unexpected irregularities in the orebody as it is disclosed by mining. When a block of ore is prepared for caving, a large proportion of the cost of stoping is spent, and the ore must be accepted as drawn.

Knowledge of the ore is essential to direct the operation of drawing, and, by comparison, to show what proportion of the ore is recovered, and how much diluting waste is drawn with it. Incorrect information on the quantity of the ore that exists and its metal content will result in poor recovery or excessive dilution.

In copper ore mined by caving, which is usually concentrated, the cost of production is less per ton and the resultant cost per pound of copper is less influenced by variations in the ore. However, even at Morenci, where the ore is mined entirely by caving, differences cause fluctuations in metal recovery or in the ratio of concentration. Ore of the same metal content may, therefore, have different values, and different limits in drawing. The selection of the ore to be mined is obtained here by laying out the boundaries of the stope and by deciding when the draw is to be stoped.

When the point of no operating profit is found for any stope, in any system of mining, it remains to be decided how little profit per ton will yield the best financial returns. The least acceptable profit per ton depends on the capacity of the plant, the proportion of overhead expense, and the invested capital. If the capacity of the plant is limited, the profit per ton must be greater, to yield suitable profits per year. This is the condition at Morenci, where ore draw-

ing is stopped considerably above the point of no profit. Metal market conditions may limit the copper to be produced. In that event, also, better profits can be obtained only by mining and treating higher-grade ore.

If for any reason spare plant capacity exists, and added copper production is permissible, total profits are increased, and the value of the mine as well, by adding to the production of average ore, not displacing it, less valuable ore which still leaves a profit after direct operating costs are paid. If the overhead charges are high, it will even pay to mine ore that does not cover full operating costs, but that does earn enough to pay a good share of the overhead expense. The Old Dominion company, with scattered operations, and heavy charges for exploration and pumping, is a case in point.

To summarize, it may be said that every orebody having individual characteristics must be studied to ascertain what its operating profit may be, based on its mining and treatment costs and the valuable metals that can be recovered, and its influence, whether mined or not, on the total profits.

Promoting the Use of Copper

By Frank Ayer

Manager, Morenci Branch

THE COPPER industry, in common with many other industries, found itself at the close of the war with plant and facilities for production far in excess of the normal consumption of copper. The industry still has hanging over it a huge potential productive capacity, and it is only because of the policy of some of the large producers to curtail production that prices, although comparatively low, are at levels which permit of a return from the investment in mines and plant. Naturally, if the consumption of copper were greater than it is, the various producers could increase production, with resultant decrease in unit cost and increased profits. A corollary to this situation was a concerted effort on the part of some of the large copper producers, through an organized plan of research and advertising, to create a broader field for the use of copper and copper products. Although the object of this was to stimulate a greater demand for copper in the open market, it would seem good logic for the industry itself to practice what it advertises and utilize copper products wherever possible in its own operations.

In 1925 Phelps Dodge Corporation initiated the policy of promoting the use of copper and copper-bearing materials at all its branches and in the districts where its operations are carried on. To carry out this policy effectively a general copper committee was organized at each branch of the Corporation, consisting of the manager, assistant manager or general superintendent, superintendents, and heads of major departments, and a copper committee was appointed in each major department, consisting of the superintendent or department head and three or four key men.

At the start these committees met four times a year and carefully analyzed lists of all supplies used in their respective departments, with the view to substituting copper-bearing materials wherever it could be economically done. In all instances the use of copper-bearing materials must be economic; that is, either equal in cost or resulting in a saving over a period of years. At the general copper committee meetings each superintendent or department head reports the progress of his committee in promoting the use of copper-bearing alloys within his department, and decisions are made regarding materials on which certain or all departments are to standardize. Minutes of the general copper committee meetings show the poundage of different classes of copper-bearing materials consumed and detailed records of new uses developed for copper-bearing materials. Copies of these minutes are sent to the general manager of Phelps Dodge Corporation, the general purchasing agent, consulting engineers, and to the managers of the other branches, so that any developments at one branch are available to all. To the surprise and chagrin of all, many instances were found where copper-bearing materials could be substituted for other materials at equal cost, and in some instances the Corporation had been guilty of using many non-copper-bearing materials at actual losses.

The greatest progress was made during the first year, after which time it was found more difficult to find new uses for copper-bearing materials. Hence, the formal meetings for analyzing supplies and discussing new schemes for increasing the use of copper are now held once instead of four time a year. However, throughout the year department heads, supply men, branch managers and assistants, and the general purchasing agent are continually watching for opportunities to substitute copper products.

A few of the more important copper-bearing materials being used are: Copper and brass pipe and fixtures in permanent structures and buildings; copper range boilers for all buildings; copper cornices, downspouts, flashings, eaves, skylights; copper and bronze fly screens for all buildings; copper toilet tanks and copper floats; copper slip nipples in radiators; copper bottoms in lubricating oil tanks and cans; copper coils and backs for heating water in cook stoves; copper sprinkler heads; bronze, brass, and Kelmet metal bearings; brass hose spuds; brass valves, unions, and stopcocks on 2½-in. and smaller pipe; copper survey tags and spads; brass carbide lamps; bronze working barrels and plungers for pumps handling acid water; bronze and brass hardware throughout better buildings and houses; brass miners' checks; brass paper clips and fasteners; brass fire extinguishers. Copper radiators and copper telephone wire will be purchased whenever needed.

After many tests it has been proved conclusively that a small percentage of copper alloyed with steel or iron greatly increases resistance to corrosion. Information has been received direct from producers showing that their consumption of copper for copper-bearing iron and steel products amounts to millions of pounds each year. Some of the copper-bearing iron and steel products almost universally used as standard throughout the Corporation are: Rails, track spikes, tie plates, bolts and nuts; railroad and mine-car bodies; nails; corrugated iron; lagscrews; air and

(Continued on page 652)

Research Co-ordination

By J. Owen Ambler
Smelter Superintendent, Copper Queen Branch

THE OPERATIONS of the Phelps Dodge Corporation cover primarily the mining and beneficiation of copper ores containing various amounts of gold and silver, and to a lesser extent the mining and treatment of lead ores; but its activities cover a much wider field, shown in detail in some of the accompanying articles of this series. The operating properties of the Corporation are in various mining districts in the Southwest and in northern Mexico, in each of which the occurrence and nature of the orebodies and the method of beneficiation are different.

In connection with the varied operating problems encountered, a considerable amount of research, investigation, and test work is constantly being carried on by the operating and technical staffs of the various branches, the object being, mainly, to obtain the best possible output and efficiency in mining, concentrating, leaching, and smelting copper and lead ores, and in the operation of the extensive power plants and machines used in connection therewith. Research problems are considered to be major problems for which a definite appropriation has been granted, whereas investigations and tests are carried out by individual branches locally on monthly appropriations, or as part of the regular operations.

To be of maximum benefit to the Corporation, it was thought that such research, investigations, and test work should be closely co-ordinated, and a committee of nine was recently appointed. This committee held its first meeting on Jan. 18, 1927, the members being the general manager of the Corporation, members of the consulting staff, and certain other members of the technical staff particularly interested in and occupied with such work. The functions of this committee are primarily advisory and include:

1. *(a)* Study of research, investigation, and test work under way; *(b)* study of methods used in work undertaken; *(c)* recommendations as to improvements and extension of *(a)* and *(b)*.

2. Consideration of research problems it may be desirable to undertake—*(a)* What problems shall be undertaken? *(b)* Method of attack.

The committee feels that the principal benefits to be derived from proper co-ordination will be as follows: (1) Duplication of work will be avoided; (2) dissemination of information to all interested; (3) by lining up beforehand all such work, no important facts necessary to be obtained either from an engineering or operating standpoint will be overlooked; (4) collection of basic data applicable to other similar problems, by having investigators and test men tabulate all variables; (5) benefit of constructive comment by committee members; (6) circulation through the Corporation of an outline of proposed major tests—containing in brief the title, purpose, method of conducting test, and value of test if successful—will in many instances suggest additional data that can be obtained at slight cost, obviating the necessity of similar test work or investigation at another branch. Having a definite objective, the test or investigation will be completed before apparatus or machinery is dismantled and a write-up of the test when completed will definitely dispose of the subject.

It is felt that particular care must be taken not to injure or destroy initiative among plant operators and technicians, and so nearly all investigation and test work is initiated by the plant personnel in various branches. As the committee meets every alternate month it is not advisable to delay starting important tests until its comment has been received; but full data as above outlined are sent to the chairman, who brings them up at the next meeting for discussion.

In the past few years the Corporation has developed by its program of research, investigation, and test work the following: (1) The Forrester and MacIntosh flotation machines; (2) application of selective flotation; (3) experiments on dustless feeding of reverberatory furnaces by screw feeders; (4) increase of roaster and reverberatory capacities, and decrease of oil ratios and slag losses; (5) a new copper smelter with superimposed roasting plant has been built; (6) a new lead smelter and lead concentrator have been designed and built; (7) experimental leaching work has been started; (8) fine-grinding experiments have been carried out at various concentrators; (9) coal-dust firing has been tested out; (10) pioneer work and development of Diesel engines has been carried out; (11) mechanical shoveling and loading is being tried; (12) an anode and a degasified copper plant has been built and is in operation; (13) heap leaching is in effect; (14) tests on the tempering of drill steel and corresponding mining performances are under way; (15) emulsified oil tests have been made on Diesel engine; (16) laboratory testing work has been instituted, together with standardization of methods and improvement of laboratory technique.

As illustrative of the variety of work discussed at the meetings of the Research, Investigation and Test Committee, the following résumé is of interest:

Research: (1) Leaching—*(a)* old mill tailings; *(b)* low-grade ores; *(c)* recovery of byproducts. (2) Refined copper research; (3) lead-mill metallurgy of oxidized ores; (4) recovery of byproducts from smelter stack dusts.

Investigations and Tests: (1) *Copper smelting—(a)* Cottrell efficiency; *(b)* performance of 11-hearth insulated roasters; *(c)* alternative methods of reverberatory feed; by changed calcine bin design—use of special alloy chains for dislodging incandescent calcine, and screw feeders; *(d)* reverberatory operation—slag losses; burner design, including the use of preheated air; method of introducing converter slag; transportation of slag; converter operation—study of anode-plant operation; time study of operations; use of briquetted flue dust and precipitates direct in converters; study of oxygen efficiency; use of screened converter ore; design of crushing, sampling, and bedding plant, including study of crushing wet talcy ores to ¼ in., and study of crushing at mines *vs.* smelter. (2) *Lead Smelting—(a)* study of blast furnace design;

(b) effect of air pulsation at blast furnace; *(c)* operation of small converter on lead copper matte. (3) *Concentrating—(a)* Type of flotation equipment; *(b)* primary slimes segregation; *(c)* effect of soluble constituents; *(d)* grinding and classification—modified shape liners; substitution of balls for rods; rod size; rod load; effect of size of discharge openings; mill speed; *(f)* use of Chilean mills; *(g)* concentrate reclaiming. (4) *Mining—(a)* stoper drill test; *(b)* drill-steel heat treatment; *(c)* air-drill lubrication; *(d)* pump bronzes. (5) *Power—(a)* improvement Diesel fuel efficiency; *(b)* corrosion of boiler feed-water piping.

In connection with the work of the committee and of the branch investigation departments, considerable use is made of the facilities of the physical testing laboratory of the Corporation at Douglas, and of the microscopic departments at several of the branches, the latter being particularly valuable in the study of concentrating problems and slag and stack investigations at the smelters. In a general way it is felt that the committee method of co-ordinating research, investigation, and test work throughout the Corporation has worked most satisfactorily.

Smelter Research

By J. Moore Samuel

Head, Investigation Department, Copper Queen Smelter

A SMELTER investigation department is of use for the finding and disseminating of facts; its value comes from the interpretation of these facts and their application to current operations. A copper smelter is essentially an industrial plant receiving its raw materials in the form of ores as mined and concentrates that have been beneficiated after mining. These materials are processed so as to produce the valuable metal contents of the raw materials in the form of blister or refined copper.

For continued successful operation, a copper smelter or any other manufacturing enterprise must continually cope with two problems: (1) The utilization of its equipment and personnel so as to produce the required output with the use of minimum possible quantities of labor and commodities, and the minimum possible process losses; (2) the planning, sufficiently far ahead, of future operations so as to provide for changing conditions and so as to take full advantage of improvements in the art.

Neither of these problems is ever finally disposed of; this year's new, modern, up-to-date plant will be merely a "1928 Model" one year from now, and will inevitably lack the refinements of a 1929 plant. In a copper smelter, as elsewhere, a properly organized investigation department is of material assistance in the solution of both the problems of the present and the problems of the future.

To function to best advantage, an investigation department should be an adjunct to and not a part of the regular operating organization; that is, it should have no regular routine operating responsibilities, other than routine test work, but should be more or less of a free-lance organization that is able to concentrate on the solution of any current or future problem. The primary purpose of an investigation department is, of course, to make money, and it will not continue to exist in any organization unless it effects economies that are in excess of its cost of operation. The means by which it can assist in making economies are by investigation—the obtaining of full, complete, and accurate data relative to any given set of operations. Its personnel and equipment should therefore be adapted to that one purpose—the securing in a reasonable time of complete and accurate data on any subject.

The scope of operations of an ordinary copper smelter is comprehensive; it touches all branches of engineering. In general, these various different operations are in charge of men who are or who become specialists in their lines. Inasmuch as an investigation department cannot always possess specialists in every phase of smelter operation, it might seem that when troubles come, the operators themselves, by reason of their special knowledge and experience, would be the best qualified men available for the determination of causes and remedies. The individual operator's time is usually fully taken up; furthermore, he frequently starts his investigation with preconceived ideas of what the results will be. He is more likely to be the protagonist of a cherished theory than an impartial investigator.

It has been said that in any problem a statement of premises that is complete and accurate makes the statement of conclusions unnecessary. If all the factors are known and are accurately evaluated, one and only one conclusion can be reached—self-evident from the facts. Although this may be an exaggeration, the converse is true that mistakes are due to lack of knowledge of all the factors or an incorrect determination of some of them. Fact finding, like cost finding, is a specialized business in itself, requiring its own special training. It is no more logical to expect the operator to do his own fact finding than it would be to expect him to do his own cost finding. Time is saved when fact finding is turned over to a group of men who specialize in that business; the operator is thereby left free to attend to his job, instead of having to divide his attention between that duty and the determination of what is causing trouble.

Fact finding, for a copper smelter with its various operations, can never become a matter of routine. It is true that the same general system can be used throughout, but the details of how that system is applied to any particular problem will vary. Such being the fact, the success of an investigation department depends entirely on its personnel. It is not meant that a super-intelligence is needed, but that the personnel should be carefully selected and specially trained for the work. A large number of men, when they graduate after an engineering or scientific course, leave college with the fixed idea that they wish to get into a research organization, and that investigation is their particular bent. Mental curiosity is greater at twenty years than it is at forty. The man of good average intelligence, when confronted by something he does not understand, first mentally asks the question, "Why?" This is followed by an impulse to find the answer. Further study and the accumulation of ad-

ditional facts suggest the reason. Testing this out proves that it is not the correct answer. The process is repeated several times, ending in the solution of the problem. If the impulse to find the correct answer persists through several failures, the man is of the research type. Good average intelligence linked with persistent curiosity is the mental characteristic required in an investigator.

The investigation department should comprise a group of young men directed by a man of wider experience who has persistent curiosity and who is something of an educator. The investigator in an industrial enterprise must do his work in co-operation with the operators. If he fails to secure their confidence he will fail to secure their co-operation and he will fail to obtain results. The confidence of fellow workers is won by proving ability and integrity, but the winning of that confidence is made more difficult for the investigator because he is called on to pioneer or try new things, many of which will fail, thereby reducing confidence in his ability. Thus, he is always open to suspicion of being a "spotter." It is therefore essential that he admit errors of judgment freely without resort to alibis, and also that he keep his fellow workers informed of what he is doing and why he is doing it, so as to avoid all suspicion of "spotting."

The training of an investigator is training for the business of fact finding. To a good general education, training must add common horse sense, which includes the ability to observe and to connect cause and effect. Much of the fact finding will involve only the making of measurements with standard apparatus, but most problems at some stage call for the devising of special means for obtaining unusual data. To the above specifications of an investigator should be added sufficient inventive ability to enable him to plan methods of measuring the previously unmeasured.

It has been said that an investigation department should be an adjunct to but not a part of the operating department. It can have no success, however, unless it has the confidence of the operators and the benefit of their experience. By itself it can do nothing; with the co-operation of the operators it can be of help.

The Investigation Department of the Copper Queen smelter was organized in June, 1917. At present it consists of a department head, three technically trained investigators for plant work, one technically trained investigator and a helper for laboratory work (other than assaying), and from three to six men for daily routine testing.

Its work consists of: (1) Routine testing, comprising those daily determinations for the plant control that require special skill; included in this group is the daily determination of stack-dust losses, and the analysis of reverberatory-furnace gases; (2) current operating problems, comprising the investigation of the methods of one or more operating departments, for the purpose of determining the causes of and finding the remedies for unusual and excessive plant losses or unusual and excessive costs, or for the purpose of planning future plant changes; (3) development problems, comprising the planning, testing, and perfecting of new methods of operation.

The first of these, routine testing, is under the direct supervision of one of the investigators, who devotes all of his time to this work and who also makes the necessary computations of the results. Current operating problems, or development problems, are ordinarily assigned to one investigator (who is given the necessary labor to assist him), except where the problem involves observation on all three shifts, when three investigators are assigned to the problem, with equal responsibility. The most common type of operating problem comes under the head of "trouble shooting." In the study of such, one to three investigators are assigned as observers, and they and the head of the investigation department act as advisors to the operator until the trouble is rectified. In development problems, the process and apparatus is operated by the investigation department until it is on an operating basis. It is a rule of the Corporation that all major tests are conducted by investigators and not by the operators.

An investigation department has two other functions of value to the organization. The investigators are called on to solve problems connected with many departments of the plant; and, in doing so, are forced to acquire a detailed knowledge of the operations of these departments, and also of how the departments dovetail into one another. In a given time, an investigator gets a wider experience than one would who spent his time in any other department. An investigation department therefore furnishes an excellent training school for future operators. When vacancies occur in the operating departments, it supplies the organization with men who have some grounding in operations.

An investigation department obtains a great deal of data. Some of it, of course, is of only passing interest, but from the mass can be winnowed facts that should be part of the mental equipment of all the men, if efficient operations are to be maintained. The sifting of this mass of data down to the essential basic facts, the presentation of these facts to all the men in simple and readily understandable form, is a service that an investigation department can perform. It is one that results in a gradual improvement in technique.

Promoting the Use of Copper

(Continued from page 649)

water pipe—all sizes; steel tank sheets; barbed wire; galvanized wire; culvert pipes; wheelbarrow shells; expanded metal lath; ventilating pipe. Many other copper-bearing articles are being used, the listing of which is prevented by the limitation of this article.

The Phelps Dodge Mercantile Company, which operates stores at the various branches of the Corporation, carries a line of copper ornamental articles and household materials, which are displayed, and their sale is pushed. Many people coming to the copper districts desire to send copper gifts and souvenirs to their friends, but too often it is impossible to find copper wares of any description in stores. Experimental work is being carried on at the several branches to determine definitely the feasibility of extending the use of copper to new fields, one of the more important tests under way at present being the use of copper flues for locomotives. Should this test prove successful it would open a large field for increasing the consumption of the red metal.

As a result of the active interest taken throughout Phelps Dodge Corporation during the last three years, the several branches have effected increases in their consumption of copper alloys ranging from 90 per cent to over 300 per cent. Actual expense attached to the organization plan outlined has been almost nil. The idea is simply to create an interest, which the employees carry along throughout the year without interfering with their regular operating work, and with this interest in their own industry they become more loyal men.

The advertising campaign and the work done by the Copper and Brass Research Association have accomplished remarkable results, as shown by the large increase in the consumption of copper during the last eight years. Should copper producers be willing to give more active co-operation to the Copper and Brass Research Association, through the adoption of some program similar to the one described above, it is conceivable that the Association would be willing to serve as chairman of an organization consisting of one representative of each of the large copper producers, refiners, and manufacturers. These representatives would send in reports describing all uses developed for copper products at their respective properties, summaries of which could be broadcast to all copper producers, refiners, and manufacturers, through the bulletin of the Copper and Brass Research Association or by separate sheets. By some such methods the copper industry as a whole might develop many new uses for copper and would consume more of its own product.

Control and Testing

By L. L. McDaniel
Chief Chemist

MOST present-day organizations in the mining industry feel the need of obtaining and utilizing to the fullest extent all facts in any way related to the final cost of their products. To fill this need in certain definite particulars the Phelps Dodge Corporation about five years ago organized a special testing laboratory as a department of the Copper Queen smelter laboratory at Douglas, Ariz.

The testing laboratory obtains information regarding the physical and chemical properties of materials and supplies used by the branch organizations of the Corporation and investigates various matters pertaining to control of technique and cost of operations at the branch plants. Copper Queen's smelter laboratory makes the usual routine determinations in connection with copper and lead smelting operations.

The Phelps Dodge testing laboratory was established in 1923 and has since continued to develop in response to an increasing demand for more detailed information regarding supplies, materials, and matters of interest to the Corporation branches. Not only the volume of work handled but the variety of work has steadily increased since the initiation of the work of the testing laboratory, and the department is now constantly occupied with general testing work and with the investigation of problems connected with the control and improvement of metallurgical operations.

The various activities of the testing laboratory are included under the following heads:

1. *General Testing Work—(a)* Iron, steel, copper, lead and alloys; *(b)* fuel and lubricating oils, coal and coke; *(c)* flotation reagents, organic and inorganic; *(d)* water and solution analyses; *(e)* miscellaneous industrial testing.
2. *Investigating Causes of Trouble and Failure of Material.*
3. *Developing and Checking Specifications.*
4. *Control of Foundry Castings.*
5. *Research Problems.*
6. *Control of Routine Laboratory Technique — (a)* monthly control of routine analytical work; *(b)* standardization of methods; *(c)* preparation of standard samples; *(d)* development of special analytical methods.

The foregoing outline of the work of the testing laboratory may be elaborated upon to show the value to the Corporation of such work.

1. General testing work is usually performed at the specific request of the operators or engineering staff. Information derived from this source is of assistance and value in selecting the best and most economical material for any particular work, and in maintaining established operating standards. The value of this control should be readily apparent.

2. The testing laboratory function of investigating causes of trouble and failure of material has a wide field of application and is usually productive of information of decided value to the operators. Failures or losses due to faulty material or to the use of improper material or methods are detected and remedied.

3. The work of developing and checking specifications is of importance in that it furnishes a means of insuring that the quality of materials purchased will be maintained at the standard agreed upon.

4. The Copper Queen smelter operates a foundry for the production of iron and brass castings for local plant use and for use by other branches of the Corporation and by outside concerns. Control of foundry castings and the production of special formula metal castings improve the service obtained from material of this class. This is of particular importance with reference to large castings such as grinding-mill liners and Diesel-engine liner bushings, which are items of considerable expense. Cupola charges are calculated and castings are checked up for composition and structure.

5. Research, involving the investigation of such problems as heat treatment, metallurgical processes, and use of new material, is of positive value in making available information upon which to base improvements in existing practice.

6. Control of laboratory technique by systematic checking of routine work assures the maintenance of high standards of work in all laboratories participating. Control of routine is obtained by monthly check work on composite samples received from all branch laboratories, seven in number. Monthly statements are issued showing comparative results reported on these samples, and any discrepancies are immediately investigated.

Routine analytical methods have been standardized and are available for reference in all branch laboratories.

The use of standard samples in the control of daily routine work precludes the possibility of constant errors creeping into the work by the use of faulty methods, faulty technique, or impure reagents. Standard samples are prepared by cooperative work on the part of a large number of laboratories, industrial and umpire, in determining true values for the samples. The development of special analytical methods for unusual and intricate determinations is of considerable aid in carrying out investigations on complex metallurgical problems.

In general, the value of the special testing work has been demonstrated from both the technical and financial viewpoints. New problems are continually arising and new opportunities for extending the scope of the work are continually presenting themselves.

The Copper Queen smelter laboratory has undergone remodeling several times since its original construction 24 years ago. Changes in laboratory arrangement were necessitated by changes in plant metallurgy, including the replacement of blast furnaces by reverberatory furnaces and the recent addition of a lead plant. Furthermore, the decision to establish a testing department in the laboratory necessitated redesigning a part of the building for this purpose.

The laboratory and general office buildings are situated just outside the entrance to the smelter grounds. The laboratory is a single-story building with attic and basement, constructed of red brick and with a slate roof. An oil-fired heating plant, a store-room for chemicals, and a motor-generator and storage-battery room are in the basement. Exhaust blowers for the ventilating system are in the attic. The outside dimensions of the building are about 120 x 45 ft. The routine laboratory

occupies the south end of the building, and the testing laboratory, the north end.

Ceilings are unusually high. In fact, over a large part of the building the ceiling extends to the roof, thus materially assisting in ventilating the laboratory and maintaining comfortable working conditions. The walls and ceilings are painted white, and the hoods, tables, and wainscoting in the analytical rooms, blue-gray. Wainscotings in the office and balance room are varnished. Inside partitions have been removed wherever possible. Where partitions are necessary they are constructed largely of glass.

Tables, all of which are supplied with hot and cold distilled water piped from a central water system, are of pine, in some instances covered with slate tops. The water system is practically automatic in operation and is elevated about 15 ft. above the laboratory floor. Distilled water is stored and heated in 50-gal. stoneware crocks and is distributed to the work tables in block-tin pipes.

Sinks are made of acid-proof stoneware. One large sink, used for disposal of solutions carrying noxious fumes, is provided with a hood leading to a forced-draft ventilating system. This sink is also provided with a compartment for hydrogen sulphide generators and another compartment for the cooling of solutions giving off disagreeable fumes. Waste solutions are disposed of through lead drain funnels near each hood. Steam and gas lines are available at convenient points in the laboratory, and an electric muffle furnace, used for fusions and ignitions, is placed in a small room with connections to the forced-draft system.

The installation of a modern forced-draft ventilating system was completed about a year ago. Fume hoods, of which there are eight, are constructed of "transite" board (pressed asbestos and cement) and steel. They are connected to two exhaust blowers by ducts of the same material as the hoods. Two roof ventilators, for removing fumes generated outside the hoods, complete the ventilating system. The hoods are equipped with electric hot plates and are supplied with low-pressure air connections.

The electrolytic room is on the west side of the building. Equipment is of the stationary electrode type, and is constructed of aluminum, nickel, and wood. Interruption of the current in each cell is controlled by nickel plugs of the telephone jack type. Electrode contacts are in the form of clothespin clips, an idea originated by F. G. Hawley, chief chemist, International Smelter, Miami, Ariz. A parallel-current arrangement, which I first observed in the laboratory of Ledoux & Company, 99 John St., New York, is used to minimize the loss of copper by re-solution at the time of removing the cathodes.

The fire room occupies approximately the central part of the building. Its equipment consists of five oil-fired muffle furnaces surmounted by sheet-iron hoods connected to stacks projecting through the roof. Natural draft is relied upon for removing smoke and fumes from this room.

The testing laboratory, in the north end of the building, was made over from an unused portion of the laboratory that originally housed the coal-fired assay furnaces used at that time. This end of the building is painted white over the rough brick surface, as no plastering or ceiling is needed. Excellent lighting is obtained through large windows and skylights. Equipment includes all necessary apparatus for testing fuel and lubricating oils, coal and coke, iron and steel, cement, and almost all other materials of construction and operation. Microscopic work in connection with iron, steel, alloys, and metallurgical products is carried out under the direction of the Copper Queen Investigation Department. Photographic equipment, including motion-picture cameras and projectors, finds constant use in this department.

Phelps Dodge Enters the Lead Business

By H. J. Bishop
Ore Buyer, Copper Queen Branch

ALTHOUGH in the last five years the average annual copper production of Arizona has been 342,100 tons, or 42 per cent of the total United States production, the lead produced was only 9,800 tons, or 1.5 per cent of the total United States production. Of this lead production in Arizona, Phelps Dodge has produced an average of 2,860 tons per year, or 29 per cent of the total from the state. These ores came almost entirely from its Bisbee mines. Prior to 1927, lead ore had been produced by the Copper Queen Branch in greater or lesser quantity for at least a quarter of a century and shipped outside the state for reduction when market conditions were favorable.

Lead ore appears to be widely scattered over Arizona, New Mexico, and Sonora, Mexico, as will be seen from the accompanying map showing the principal railroad shipping points. Lead production in the Southwest has been steadily increasing since 1921, but few properties have been actively developed on a large scale, probably owing, in part, to lack of conveniently situated reduction plants. The abandonment by Copper Queen, late in 1926, of its copper blast furnaces and parts of its old roaster and reverberatory plant at Douglas gave Phelps Dodge the opportunity to construct a lead smelter at reasonable cost by utilizing to good advantage certain facilities no longer required. The new plant was completed and blown in on Aug. 18, 1927.

Previous attempts at lead smelting (none, however, during recent years) had been made by other interests at various places without permanent success. Inadequate development of a dependable source of supply of ores and cheap fluxes, as well as small size of plants built, were no doubt factors largely responsible for their failures.

The essential features of the Copper Queen lead smelter comprise a modern

automatic ore-sampling plant, with conveyor belts for delivery of ore and concentrates to current smelting mixtures; conveyors and elevators for reclaiming and delivery to charge bins above the furnace charge floor level; a Dwight and Lloyd sintering machine: one 48 x 192-in. blast furnace; one nine-hearth Queen-type roaster; and a converter for leady-copper matte. Also, large flues, a dust chamber, a baghouse, a 300-ft. brick stack, and bullion kettles and molds. All units are electrically driven and substantially constructed of steel, brick, and concrete. Many of the units are of ample size to accommodate the operation of two furnaces. Gases from the sintering machine, blast furnace, and converter, as well as fume from settlers and matte pans, which are hooded to prevent escape of lead-laden gas, pass through flues to the baghouse. White metal produced by the converter is transferred to copper department converters. During the first half of this year the furnace charge has averaged 15 per cent lead, and the average monthly production of lead in bullion has been approximately 1,400,000 lb.

The lead plant is operated as a bonded warehouse under the supervision of a government inspector, to facilitate handling of ores and concentrates coming from Mexico. Bullion is shipped to the Balbach plant of the American Metal Company at Newark, N. J., for refining. Ores and concentrates treated from the Copper Queen mines and independent producers cover a wide range in character, receipts of custom ores to date coming from over 100 widely-scattered shippers and representing a tonnage equal to the forecast, notwithstanding a decline in the lead price. Lead content ranges from almost nil to as high as 78.5 per cent, with corresponding variations in slag-forming elements and sulphur. The average lead content of all receipts has been slightly above 20 per cent. Ores and concentrates of lower lead content usually assay high in gold or silver, or in both. In fact, these precious metals play an important part in the mining and concentrating operations of many of the Southwestern mines, particularly those in Mexico.

Bullion produced has average well over 1 per cent of silver to date. Insoluble elements are, on the whole, present in excess of the requisite bases, so that a certain quantity of limerock must be supplied to furnish the necessary flux to make a clean, fusible slag. The presence of certain elements frequently contained in lead ores makes the smelting operations more complex and expensive. Although a certain percentage of copper is recovered, its presence is responsible for increased lead loss and necessitates roasting, sintering, and concentration runs to bring the first-run matte up to a suitable grade for converting. Zinc is an undesirable element, as almost all of it must be removed as an oxide in the slag; and, moreover, when present in excess of certain small percentages, it requires the addition of scrap iron to the furnace charge. Antimony and bismuth are the chief offenders among the impurities encountered so far. Both have decidedly detrimental influences, bismuth being particularly objectionable. The presence of either in lead bullion greatly increases refining costs.

Treatment by direct smelting of a rather large proportion of the low-grade carbonate ores at the Copper Queen mines is unprofitable at low lead prices, owing particularly to their high insoluble content. Experimental work in the laboratory and test runs on a large scale in a neighboring mill indicated that the ore was amenable to concentration. A mill of 200 tons' daily capacity was built at Warren at the same time the smelter was under construction. The principal features include unloading pockets, coarse crushing, automatic sampler, storage bins, ball mill, classifier, two sets of flotation cells, settling tanks, and filter.

Both Copper Queen and custom ores have been milled, the major part of the tonnage handled during the first year's operation coming from other producers at Bisbee. Particular attention was given, for this reason, to provide track scales and accurate mechanical sampling facilities. The ores milled are principally low-grade, with some gold and silver, the lead occurring almost entirely as a carbonate. A considerable proportion of the gold and silver content is associated with the gangue constituents rather than with the lead. The primary float contains most of the gold and silver and any galena contained, and runs high in insoluble, whereas the second or sulphidized float runs high in lead, with low precious metals and insoluble. Sufficient storage capacity is provided to enable the operators to make laboratory tests from mill samples and, if necessary, to adjust the proper reagents before the crushed ore is drawn from the bins.

The combined concentrate production has averaged about 40 per cent in lead and less than 25 per cent insoluble. Much better recoveries have been obtained from the hard, clean, coarse ores than from the softer, fine ores, which contain a higher percentage of oxides of iron and some manganese. These latter more refractory ores have been investigated; and, by the exercise of microscopic control, to determine various ore characteristics and composition of the lead minerals, recoveries have been improved on some of them.

Although present low lead prices are not particularly stimulating to small custom-ore producers, there has been, in the last year or so, a decided quickening of interest in the development and mining of lead ores, resulting in many instances in the erection of small lead concentrators. If only a small part of the money spent in the last few years in searching for copper mines were to be expended in the future on looking for lead ores and lead-zinc ores that can be selectively treated, the prospect for greatly increasing the lead production of Arizona, New Mexico, and Sonora would be bright.

Economy in Equipment Usage

By W. M. Saben
Assistant Manager, Morenci Branch

ON ACCOUNT of the conditions existing in the copper market, the various Phelps Dodge Corporation branches ceased production in 1921. Some of the branches continued development; some stopped all operations. Before production was resumed in 1922 the Corporation had acquired another property adjacent to one of its branches, which property a few years previous had acquired still another adjacent property. There was, therefore, considerable surplus equipment on hand at these newly acquired properties.

At two other branches, the concentrators had been remodeled to conform to the latest milling practice, thereby releasing considerable equipment no longer suitable for their operations. As all of the properties, with the exception of one, would be considered old properties, much miscellaneous equipment, for which the various branches saw no use at their respective properties, had accumulated at each one. In addition the Corporation had stocks of supplies on hand at the beginning of 1921, valued at about $4,500,000. These stocks did not represent a well-balanced supply, but reflected the effects of war-time buying, when overstocks of certain commodities were often purchased in order to play safe, as it was difficult at times to get supplies when needed. These stocks also included material that had become obsolete so far as its particular branch was concerned, as well as what may be called surplus stocks of usable supplies. The quantity of so-called insurance material, which is always slow-moving, was also large in proportion to the total live stock.

Realizing the unnecessary amount of money tied up in these stocks and in equipment no longer being used, the general manager issued the following bulletin:

"Savings can be effected by: (1) Salvaging old material on the plant and using it over again; (2) substituting from stock, even though the material is not just what is wanted, rather than ordering new material; (3) transferring from other branches whenever possible, instead of buying from the outside; (4) insisting on no waste of supplies on the plant; (5) scrutinizing every single order you send out for new material and making certain the same is absolutely necessary; (6) standardizing supplies so far as is practicable."

The Purchasing Department at this time was in New York, and therefore not intimately acquainted with all the details of the stocks on hand at different locations. The first step taken to balance the stocks was to take a man from the Purchasing Department, have him personally look over all the stocks, and then have him locate in the West. Then, instead of sending orders direct to the main purchasing department, all orders were sent to this Western representative, whose duty it was to compare these orders with the stocks of similar material on hand at all the various branches, and if possible to fill these orders from surplus stocks.

In the first two years of this arrangement the value of supplies so transferred between the branches amounted to nearly $400,000, or about 9 per cent of the total value of the stocks. Almost all this amount may be considered as having been taken from surplus material on hand.

The next step taken was to attempt to realize cash from the large amount of obsolete equipment at every property. An arrangement was made with a dealer in second-hand machinery whereby on a commission basis he would attempt to dispose of such equipment. Within two years he succeeded in selling a very large proportion of the marketable material, thereby adding to the cash reserves of the company, as well as helping to clean up the locations where this old material had been piled, some of it for many years.

The next step was to encourage the use of such equipment and material at the other branches, by allowing them to obtain it without charge except the cost of loading onto railroad cars. When it was realized that something could be obtained for almost nothing, the various branches found use to a surprising degree for material that the branch owners had considered either worthless or had no immediate use for. The value of such material transferred free of charge, together with a small amount sold outside, amounted to $350,000 in three years, which amount may be considered as representing a saving to the company.

The direct effect of these various arrangements can be realized better by the value of all supply stocks on hand today, which is less than 50 per cent of what it was six years ago, although even now a small amount of surplus material is on hand, which, however, is being slowly reduced each year.

Other effects of the various instructions listed above may be realized from the following: At one branch not a rail has been purchased for eight years, although the underground operations at this branch have been considerably expanded. No pipe over 2 in. in diameter has been purchased during the same period. In this connection it might be mentioned that for pipe approximately 3 in. in diameter discarded boiler flues have been used, the curved portions being burned off and either nipples being welded on or various lengths welded direct. Discarded buildings and tanks have gone into repairing and reinforcing cars. Cleaning up the material on the slag dumps disclosed other material that had been forgotten for years. If no other possible use could be found for it, the material was sent to the foundry, where the scrap so accumulated has furnished the grinding media for one concentrator for five years, and will continue to furnish it for several more years.

Substituting from stock has been an

(Continued on page 668)

As Recorded By the Camera

Sacramento Hill in 1904. Prospecting by churn drill preceded removal of 20½ million tons of waste rock.

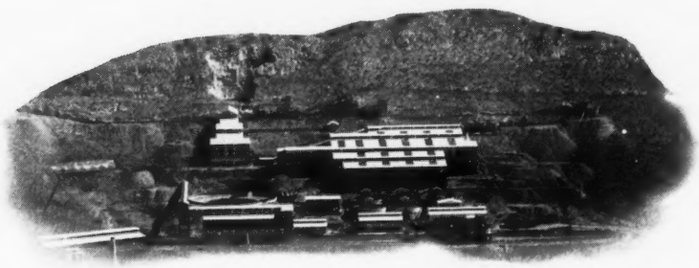
Sacramento Hill in 1928, after the removal of 10 million tons of ore, averaging about 1.7 per cent copper

General office,
Copper Queen Branch,
Bisbee, Ariz.

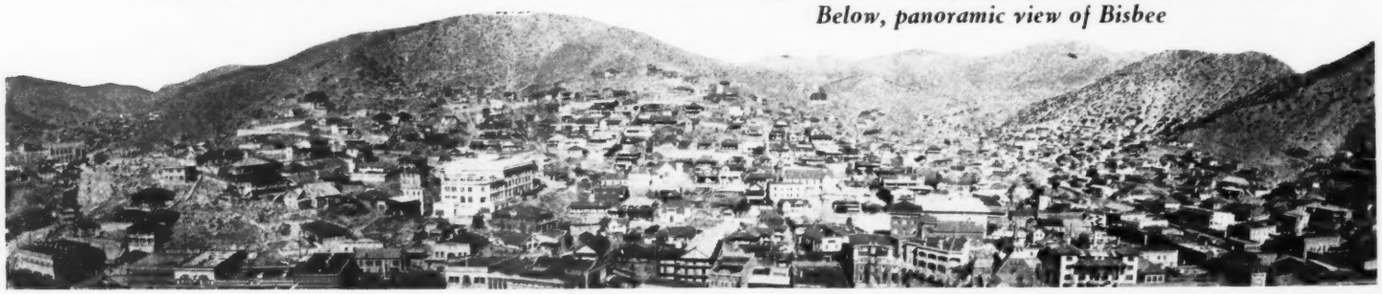
Main Street, Bisbee
At the left is the library, maintained by the Corporation

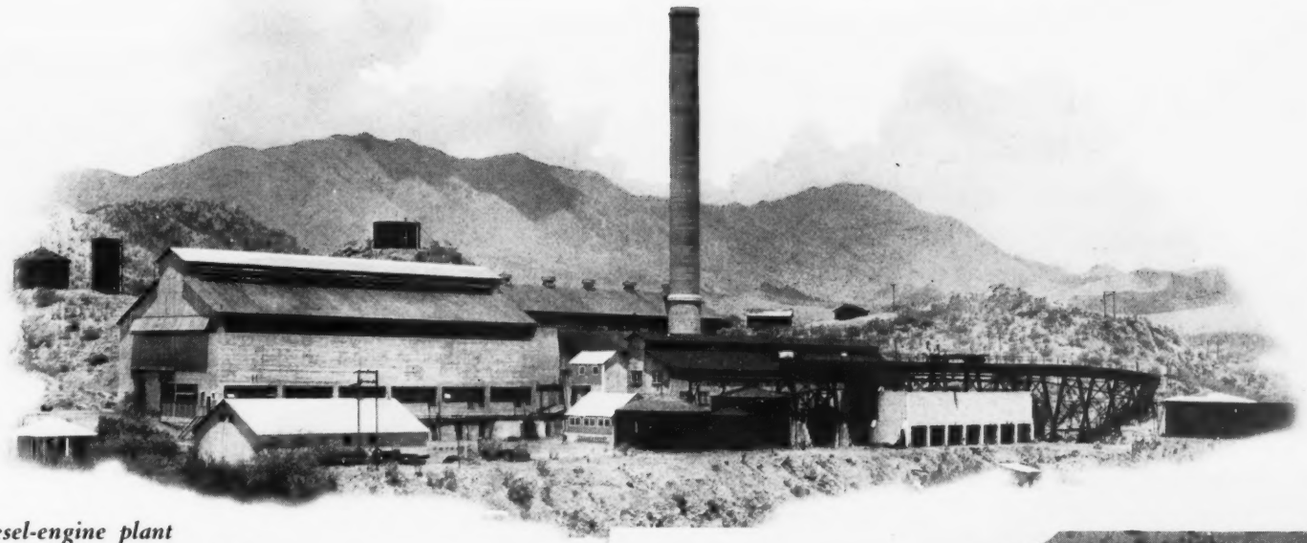
Y. W. C. A. building, Bisbee

Copper Queen Hotel, Bisbee

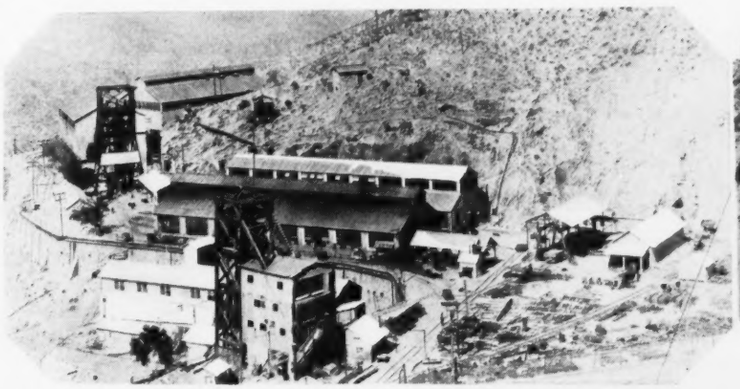


Concentrator and Diesel power plant, near Warren, Ariz.
Below, panoramic view of Bisbee

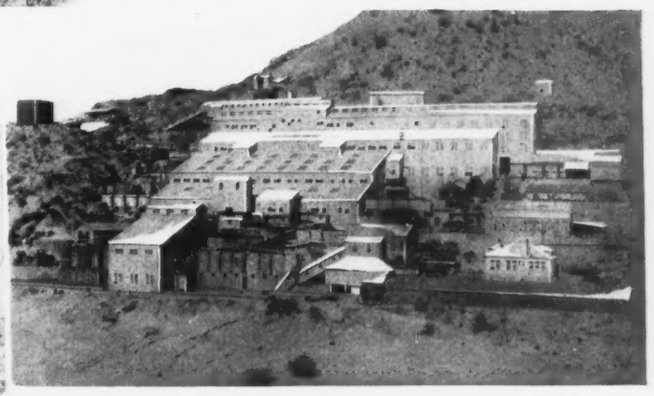




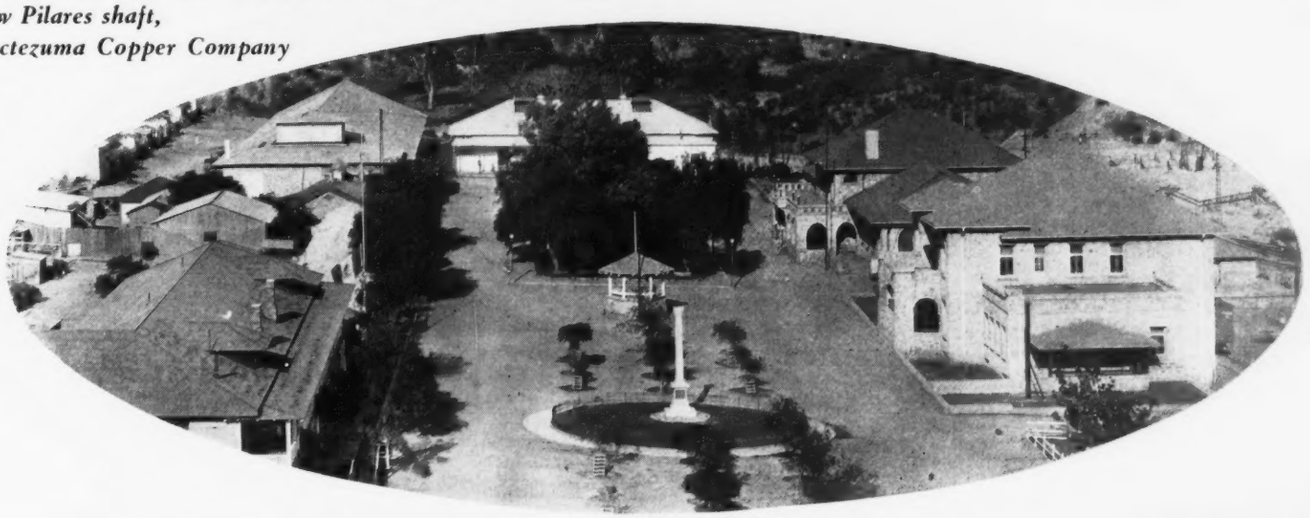
Diesel-engine plant at Nacozari, Sonora, Mexico



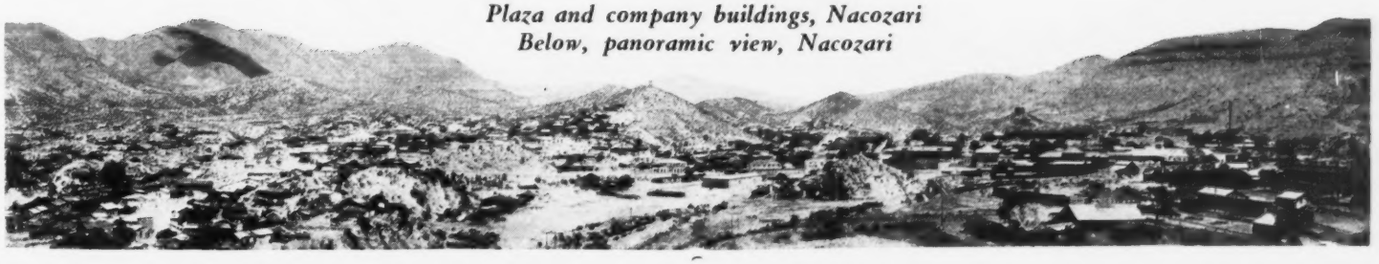
New Pilares shaft, Moctezuma Copper Company

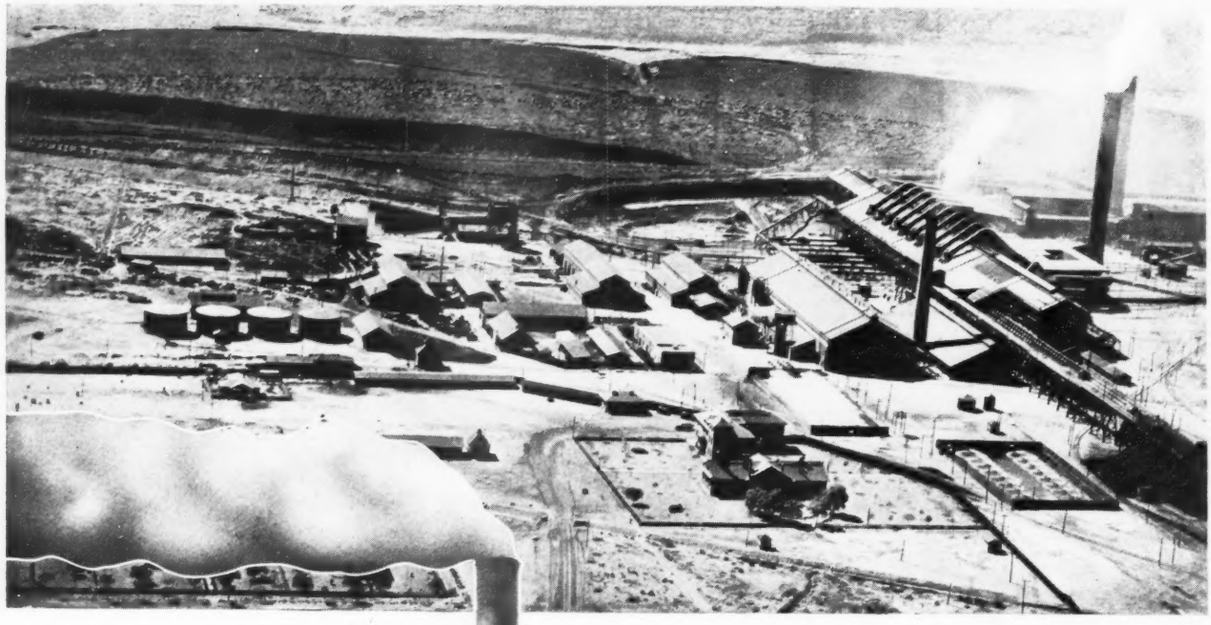


Concentrator at Nacozari

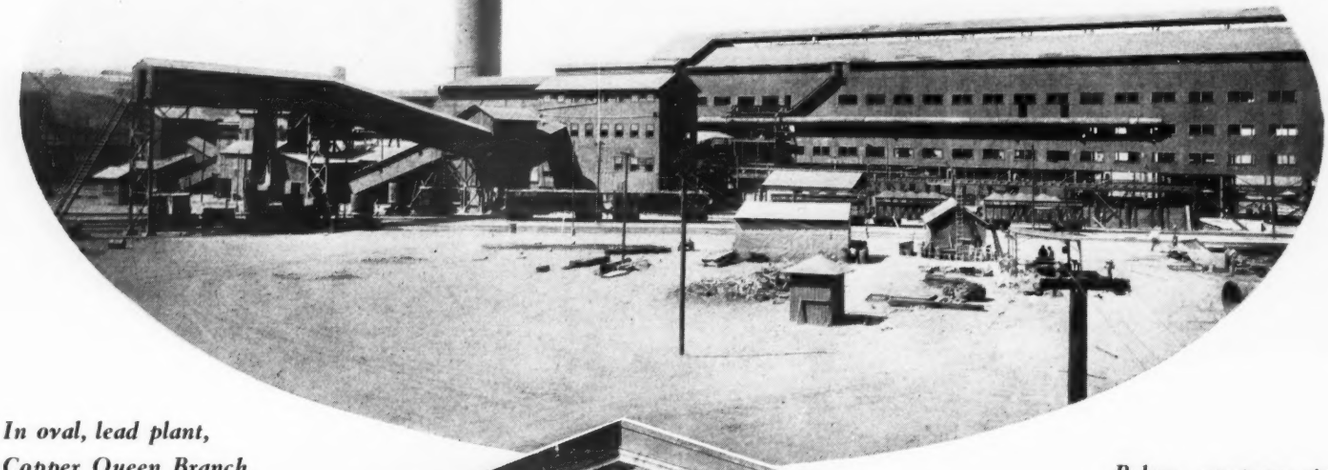


Plaza and company buildings, Nacozari
Below, panoramic view, Nacozari





Airplane view of reduction works at Douglas, Ariz.



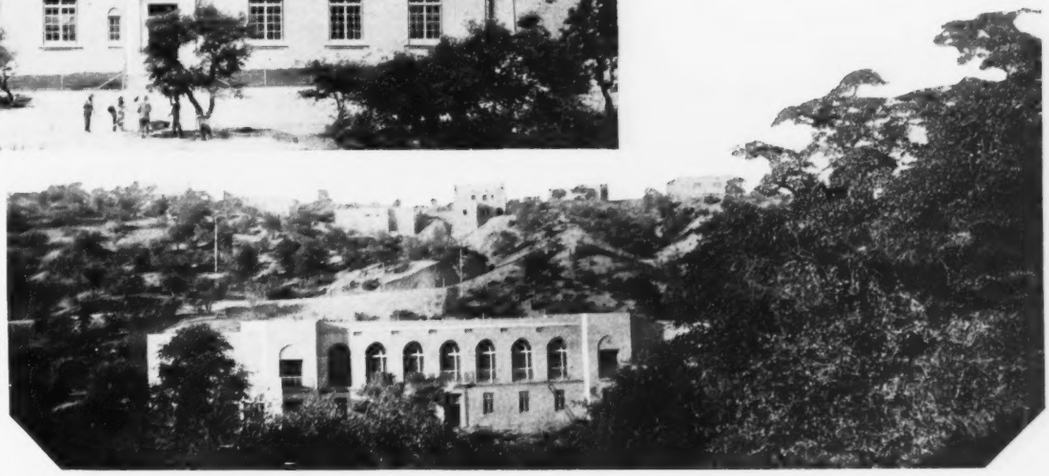
In oval, lead plant, Copper Queen Branch, Douglas

Below, company store at Douglas

T. S. Parker Hospital, Burro Mountain Branch, Tyrone, N. M.

General offices, Burro Mountain Branch

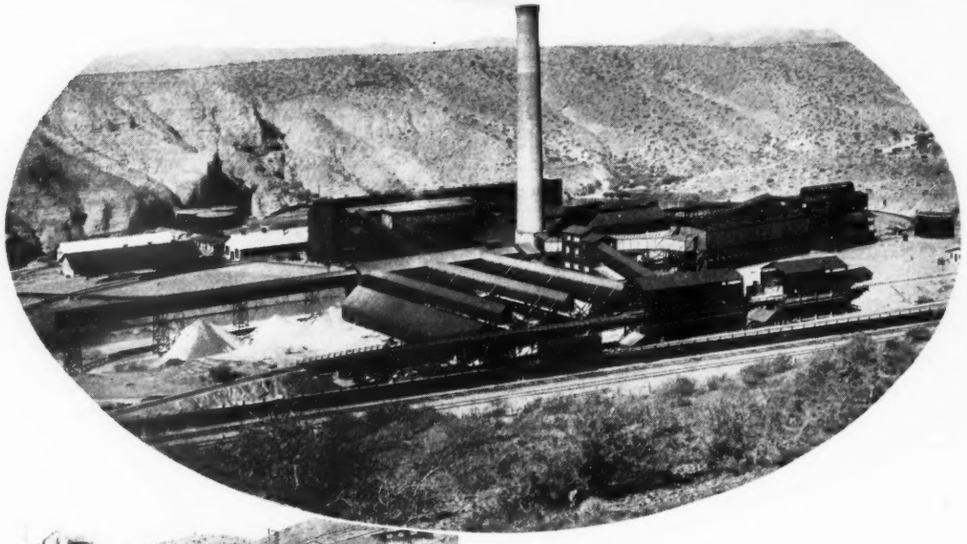
School at Tyrone, N. M.



Bunker Hill mines, Tombstone, Ariz.

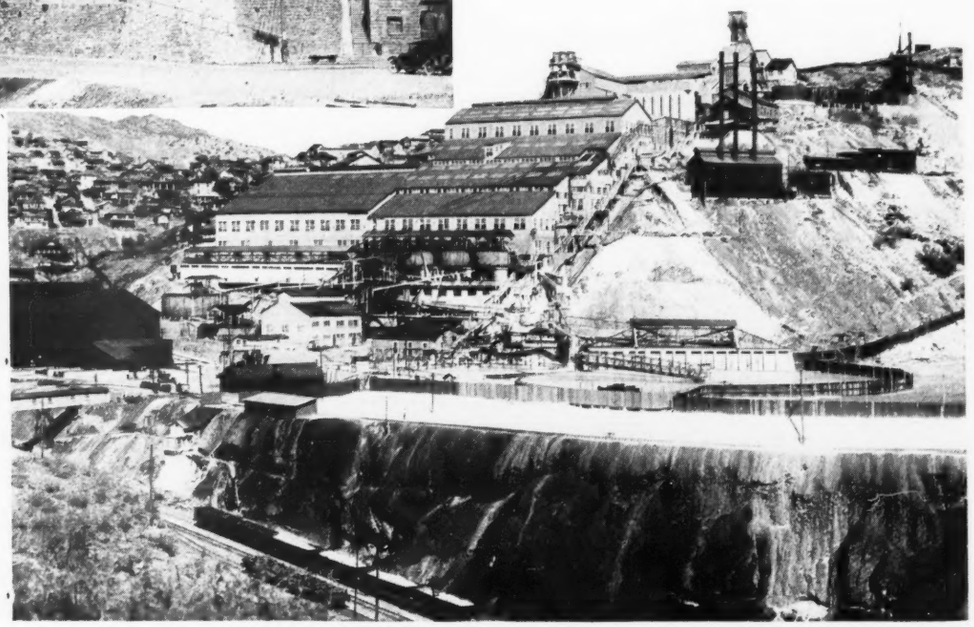
Above, Morenci, Ariz.

In the oval, smelter at Clifton, Ariz.



Morenci Hotel, with school at left

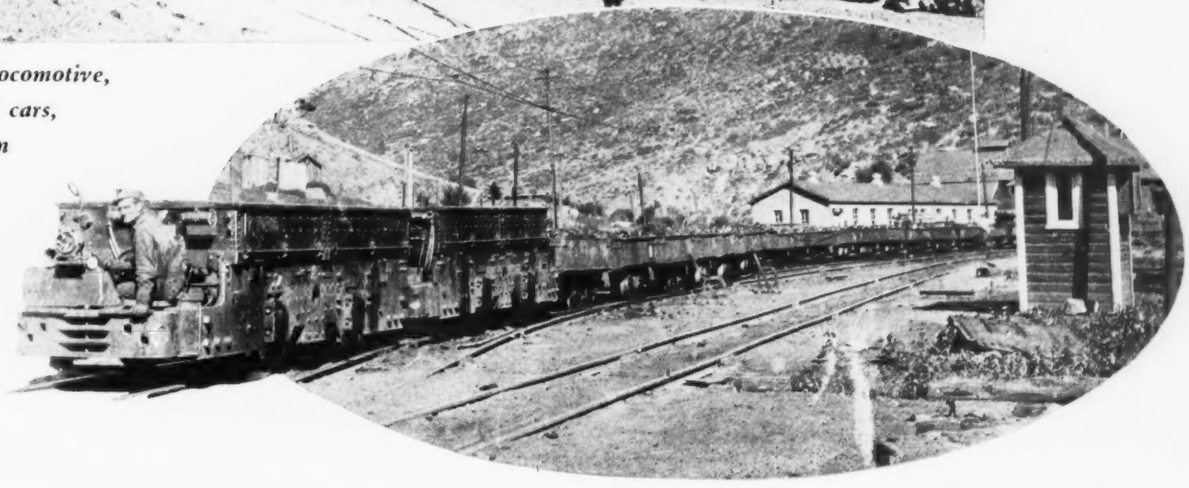
At the right, concentrator, Morenci Branch



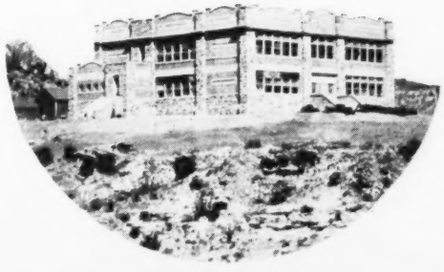
THE PHELPS DODGE ENTERPRISE

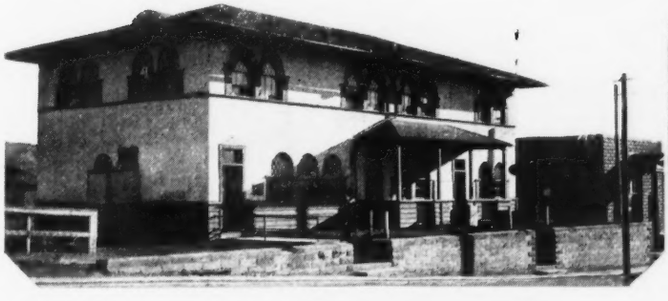
Tipple and coal bins, Stag Canon Branch, Dawson, N. M.

Storage-battery locomotive, with train of cars, at Dawson



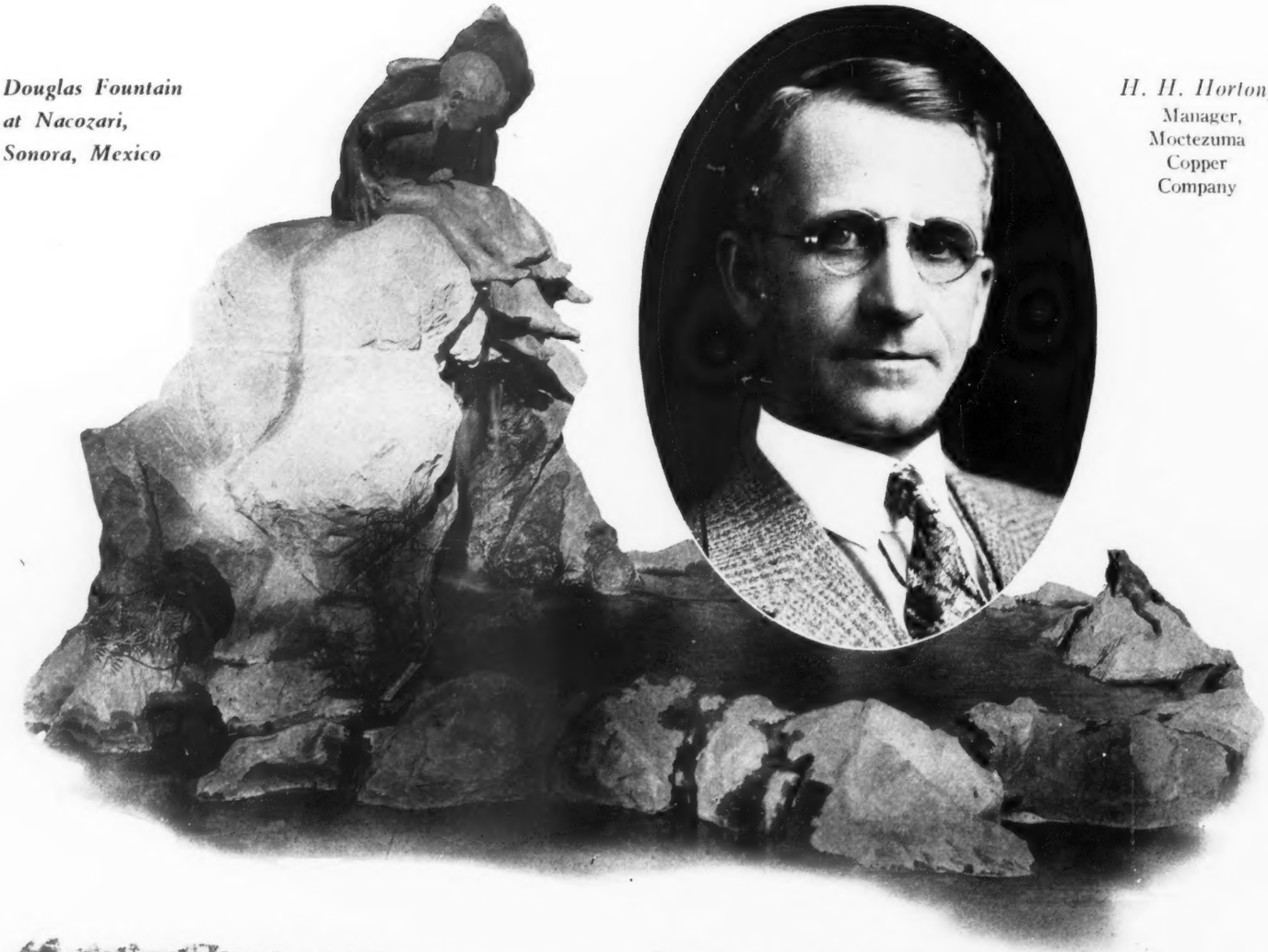
In circle, Douglas school, at Dawson





At left, general offices, Dawson
Above, hospital at Dawson
Below, mine, mill, and smelter of Old Dominion Company

THE PHELPS DODGE ENTERPRISE

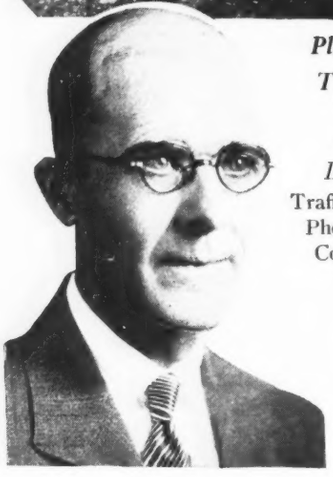


Douglas Fountain at Nacozari, Sonora, Mexico

H. H. Horton, Manager, Moctezuma Copper Company

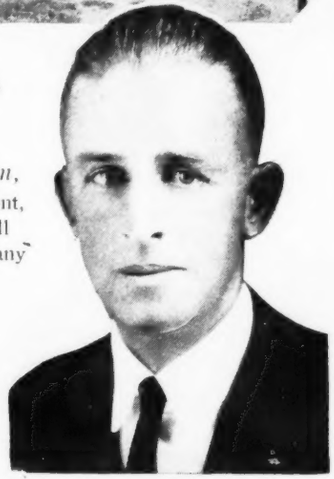
Plaza and store, Tyrone, N. M.

School Tyrone, N. M.



C. C. Lassiter, Traffic Manager, Phelps Dodge Corporation

W. D. Brennan, Manager, Stag Canon Branch



F. H. Soderstrom, Superintendent, Bunker Hill Mines Company

Mine Development

By I. H. Barkdoll

General Manager, Old Dominion Company

IN THE mining accounts of Phelps Dodge Corporation branches, all development work is divided into (1) exploration and development, and (2) stope preparation. The first classification includes all work necessary to prepare and outline ore so that accurate estimates can be made. It includes shaft and winze sinking, main-haulage drifts, and enough crosscuts and raises to give positive information on tonnage and average metal content. In a general way this is level development, although occasionally, in a completely developed section, level work is charged to stope preparation. The second classification includes all work other than the preliminary development. It is mainly intermediate work. Special raises and shafts for ventilation or pumping are driven on separate accounts, but ultimately the cost is assignable to direct development. Only the classification of exploration and development work will be discussed in this article. The work under this heading exceeds 100,000 ft. per annum.

Geological Work as Related to Development

All the Phelps Dodge branches maintain geological departments. The duty of the department at the Old Dominion is to map all geology, both surface and underground; to direct the sampling of advance development work; and to furnish estimates of both the grade and tonnage of all ore developed; to plan in advance all development; and to prepare maps of the proposed work with an estimate of progress to be maintained. These maps are brought up to date monthly, and marked plus or minus in red or green—red if the estimated advance has not been made; green if made or bettered.

New developments and the progress rates set are decided after consultation with the mine superintendent and general foreman. Any work that could be classed as a major program requires consultation with the general manager as well. No development is permitted to be started in a haphazard manner. All geological data must be used, and, if possible, the work outlined must be utilizable for stoping or extraction purposes in the event that ore is found. The geological departments of other Phelps Dodge branches follow these principles, although they may differ in details of practice.

Speed of development is vitally affected by the conditions under which the work must be done. The nature of the ground, water, and ventilation conditions are the main factors. The hardness and heaviness of the ground affect the problem less than the aforesaid water and ventilation. Inasmuch as conditions are dissimilar in the different mines, the time when new levels or areas must be opened or additional ore blocked out is a special problem for each branch. The ground at Pilares, of the Moctezuma Copper Company, is reasonably hard and uniform, requiring little if any timber. The Morenci Branch seldom encounters conditions that seriously retard estimated progress. Geological changes in formation can be determined and mapped in advance. Main-haulage drifts are occasionally timbered, but in smaller drifts no timber is necessary. The geology of the Copper Queen and Old Dominion mines is very complex. Ground is encountered that changes rapidly from extremely soft and heavy to extremely hard, and the reverse.

At Morenci and Pilares there are no serious water problems. The Copper Queen has enough to make it a problem of major importance; and at the Old Dominion the water problem is always serious and at times in the past has been out of control, owing to a series of wholly unpredictable events. From the 1,400 level down, increasingly hot water has been met. The increase from the 1,400 to 2,600 has been 10 deg. F. At the 2,600 the water is 110 deg. F. The first heading from any new level at once encounters from 1,200 to 2,000 gal. per minute. Old Dominion is thus forced to open new ground much earlier than the others in order to drain it and keep the same proportion of development in advance.

Ventilation Necessitates Mechanical Equipment

All the mines operated by the Phelps Dodge Corporation are mechanically ventilated. Special openings for ventilation, or shafts, are equipped with fans of large capacity for the delivery of fresh air into or adjacent to working areas. Either pressure or exhaust systems are used. The air is frequently picked up from the nearest fresh-air course of the primary system by smaller fans and forced into dead and development headings or other mine workings that do not receive enough air from the main circulating system.

Secondary fans are of the multivane type. They have capacities ranging from 5,000 to 50,000 cu.ft. per minute, and are used for distributing or boosting large volumes of air into poorly ventilated areas and short development drives. These at the Old Dominion are slow-speed fans, motor driven, and develop from 2 to 3 in. water-gage pressure. For ventilating development headings 500 to 800 ft. from fresh air currents, high-speed motor-driven pressure-type blowers are used. For distances greater than 800 and up to 1,600 ft. they are used with exhausters connected into the ventilating line at some point nearer the face. These blowers and exhausters are driven at a speed of 1,600 r.p.m. and develop 7 in. water-gage pressure. The volume of air delivered at the working face is governed by the size of blower and exhauster used.

Galvanized-iron ventilating pipe is used between blower and exhauster, as the pull on the line by the exhauster has a tendency to collapse the delivery pipe. A large percentage of all ventilating lines at present is of canvas tubing, ranging in size from 8 to 24 in. diameter, according to the size of the fan and the volume of air to be delivered.

Standardization Adopted Where Practicable

For several years the Corporation has been engaged in a campaign of standardization wherever similar conditions exist. All branches used methods founded on the same principles, but a complete standardization is impossible. The Old Dominion, an old and deep mine, is

limited in its haulage equipment by the size of the shafts, which were started many years ago, and its rate of production. The Morenci Branch, working a large low-grade deposit, requires larger equipment and, consequently, larger haulage drifts. Then again the economic maximum size of haulage equipment, which controls the size of development workings, is smaller for a high-grade than for a low-grade mine because the rate of production is usually smaller.

Each branch has two standard drift sizes differing slightly from those of the others. Two sizes are driven in developing—one for motor haulage, the other for hand tramming. Old Dominion, Copper Queen, and the Moctezuma Copper Company have drifts of approximately the same size—motor drifts 8 x 6 ft., hand tramming 7 x 5 ft. The Morenci Branch has much larger haulage drifts.

The sizes of raises and methods of timbering are not uniform. Each branch has worked out and adopted its own standard. At Pilares, most raises are cribbed for safety in driving and then stripped of timber, whereas this is done only occasionally at the other branches.

In double-compartment cribbed raises Copper Queen uses framed stringers of the length of both compartments. Old Dominion uses two pieces, one for each compartment, believing that such practice is safer and more convenient. Square-set raises are of standard size at all branches, and all use the same standard square set. No Corporation standard has been established for shaft or winze work. Each branch has its own, generally founded on inherited practice and equipment.

Development by Churn Drilling and Diamond Drilling

The development of the low-grade orebodies of the Copper Queen was by churn drilling. In Morenci the exploration was both by surface drilling and by underground work. The Morenci Branch and the Old Dominion have occasionally put down churn-drill holes from points underground. Underground churn drilling at Morenci was for prospect purposes only. At the Old Dominion most underground churn drilling is done for ventilation. Underground diamond drills are now being operated at Pilares and the Copper Queen. At other branches diamond drilling has not been a general practice, but it is occasionally done.

Drilling and Blasting

Drilling and blasting operations of the different branches are uniform. In drifts, a standard V-cut round is used. This is a 10-, 13-, 16- or 21-hole round, depending on the class of ground and size of opening (see Figs. 1, 2, 3 and 4). The important features of the round are the angle and depth of the cut holes and the number of V's drilled to break different classes of material. This round was developed at the Copper Queen Branch by experiments over a period of years, and was then generally adopted. All branches agree that the use of this round has simplified practice and yielded higher efficiency.

It is the policy of the Corporation to provide instructors to teach new or unskilled employees the method of drilling and blasting their standard round. In addition to this, prints and sketches are posted on bulletin boards, and models are displayed conspicuously.

Blasting operations are regulated by the wetness of the ground and the distance necessary to travel to reach a safe point. In dry, cool headings at Morenci, Pilares, and Copper Queen, safety fuse is used exclusively. In the Old Dominion, where most of the development work is in hot, wet ground, electric blasting is compulsory. Electric blasting is used at all of the branches for shaft and winze work, long raises, and wet development faces. A blasting machine is used to generate current for electric blasting in cool, dry sections of all the mines. In wet, hot areas, current is furnished from a power or lighting line. Under such conditions a blasting line is carried along as regular equipment. "Instantaneous delay" blasting caps are used in all cut holes. Different-length delay electric blasting caps are used for the remainder of the round, as the sequence requires.

The use of tamping or stemming is compulsory, because it greatly increases the efficiency of the explosive and adds a considerable safety factor to the mucking operation, and far less liability of loose powder in the muck piles. Safety is the primary consideration in blasting; it is never subordinated to economy.

From experience it has been found that 40 per cent gelatin powder is most satisfactory for general use. In very hard ground 60 and 80 per cent gelatin is used; in very soft ground only 30 per cent is necessary. In shaft and winze work it is general practice to use 60 or 80 per cent gelatin. This makes a more even bottom off which to muck, as all holes will break to the depth drilled. Also, the muck is broken finer and requires less sledging. In very hard ground, in drifting and raising, a combination is used—80 per cent for the cuts and primers and 40 or 60 per cent for completing the charge. Ammonium nitrate powders or dynamite is used to a lesser extent in well-ventilated dry mines when other conditions are favorable.

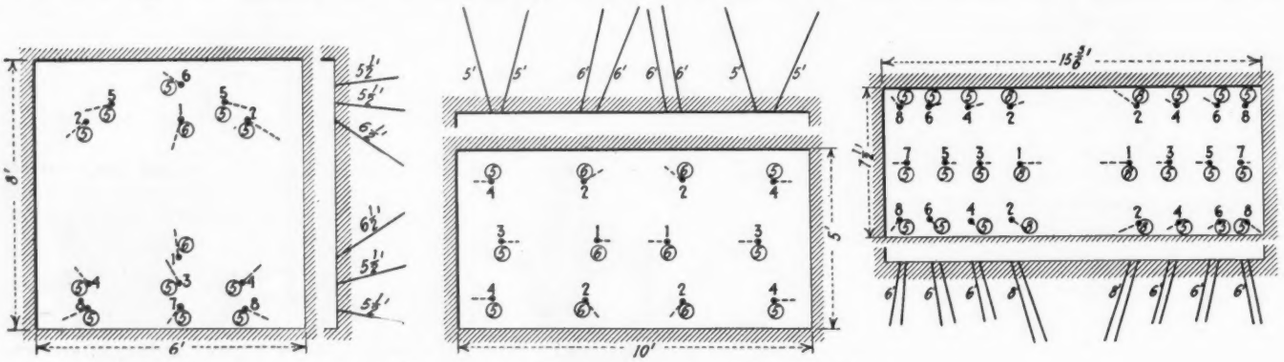
The success or failure of a program of standardization depends wholly upon supervision; therefore, all development faces are inspected frequently and carefully classified. The duty of the supervisory force is definitely to assign the round to be drilled, and not to leave it entirely to the judgment of the miners.

Methods employed and standard practices at the Phelps Dodge branches have been brought about by the free exchange of information regarding experiments, tests, and costs of different items of operation practiced through the management and heads of departments.

Development Intervals

The vertical spacing of development levels at Morenci, Pilares, and Copper Queen is at 100-ft. intervals. In the lower levels at Pilares 133⅓ ft. spacing is being introduced. In the Old Dominion, the vein is first developed at 200-ft. vertical levels.

Main-prospect drifts at the Old Dominion are driven on lines based on geological information projected from the levels above. An attempt is made to keep this drift 40 ft. within the footwall of the vein, by projecting it down from the deepest level explored. This allows sufficient distance to prevent the crushing of the intervening pillar. The experience at this property has been that, if a footwall drift 40 ft. from the vein



Standard drill rounds at the Old Dominion

To the left is shown a drift round; in the middle a raise round; and on the right a shaft round. Circled figures show the number of cartridges used; the uncircled figures indicate the order of firing of the shots.

becomes heavy, it is impossible to avoid it by a bypass drift of moderate length. It is usually cheaper to repair than go around. Crosscut intervals at the different properties are not uniform. Geological conditions are so widely variant that there is no basis for uniformity.

The ratio of development footage to tons of ore mined also varies greatly. Copper Queen and Old Dominion have used about the same ratio—1:10. A development program based on a ratio obtained from the records of several years is a guide for planning a development program (for total footage) as long as the results are concordant with those obtained formerly. At any time, however, that the results are not so good as those formerly obtained, it must be completely disregarded.

Direct comparisons of the efficiency of different classes of labor between branches is impossible, because of the great difference in conditions under which the work is done. It remains a matter of opinion, not of proof, which class makes the most efficient workmen.

Each branch uses the contract or bonus system. At some branches both plans are used to increase the speed of development work. About 90 per cent of all development work is done under one of these plans. Both contract and bonus systems carry with them an unwritten agreement that the workman shall receive a minimum wage, which is the best rate of wages for that branch.

The bonus system used is a 50-50 plan—all money made over the base or standard is divided equally between the company and the workman. The contract system is a straight contract at a definite price per unit of work. The only possible variation in this is the drawing of a new contract. Men employed on development work under these two systems earn from 30 to 50 per cent more than the base wage scale. In all development work, labor is rather highly specialized. That is, men specialize in raising, sinking, or drifting and are capable of performing all of the operations necessary in their divisions.

Thus, at the Old Dominion, in drifting where timber is required, a crew consists of two miners who can timber, drill and blast, and muck, so that the work can progress without a change of crews regardless of the stage of the operation in which the preceding shift has left the work. In untimbered drifts the crews consist of a driller and one or more muckers, usually two.

If drilling is done from a clean heading using a vertical bar, only one driller is needed. He is given assistance in setting up, tearing down, and in loading and blasting. An opposite shift of muckers cleans the heading. If drilling is done from a crossbar, the crews consist of a driller and two muckers on each shift. If a sufficient number of working places are close together, one driller is given two or more headings to drill. In raises, a crew consists of two miners on each shift, who drill, blast, and timber as the occasion requires.

Rock Drills

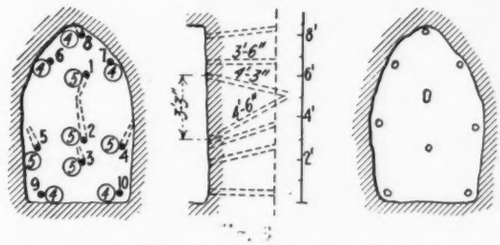
In the Old Dominion, all main extraction, haulage, and advance development drifts are driven with mounted machines. They may vary in model and make, but all are of one general type and weight (130 lb.). For smaller crosscuts and development drifts, the jackhammer type of drill is in more general use, mounted or unmounted as conditions require. Raises are driven by stoper drills, 95 per cent of which are hand rotated. All are equipped with 1-in. standard Leyner chucks for 1-in. hollow-round lugged steel.

A standard size, 3½-in. column bar and arm is used by all branches for mounting all types of heavy- or light-weight drifting machines, although a few lighter bars may still be found in use at some of the mines for mounting the jackhammer type of machine. A 3½-in. single-screw post column is standard at the Old Dominion for all classes of work and types of machines. The Pilares and Morenci standard is a 3½-in. single-screw column and double-jack bar. The Copper Queen Branch has standardized on the Saffold single- or double-screw column.

One standard brand and size of air and water hose is used by all branches, other than occasional small lots of other brands purchased for test. The air hose is constructed with an oil-resisting inner tube and must meet certain tests and specifications. Many of the branches use an automatic air-line lubricator with considerable success. Its adoption as a standard method of lubricating rock drills depends mainly upon improvements in reliability. Several of the mines use pipe fittings with standard pipe thread as a standard air-hose connection. Others use the standard spud or a lock-ring slip-type connection.

The section of drill steel generally used in Phelps Dodge Corporation mines is the 1-in. hollow round bar. After tests, this section was adopted by many of the properties as a standard for all underground drilling machines. At the Old Dominion each set of drills consists of five changes: bits are stand-

Fig. 1



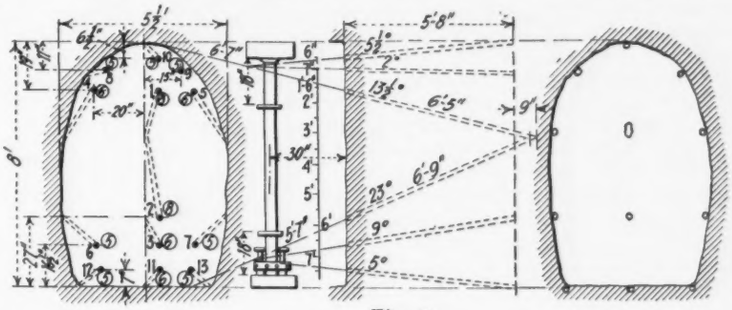


Fig. 2

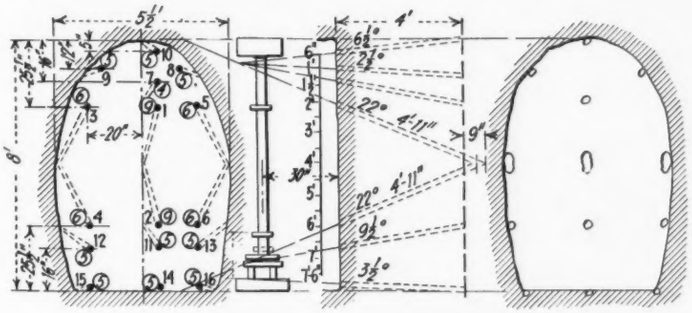
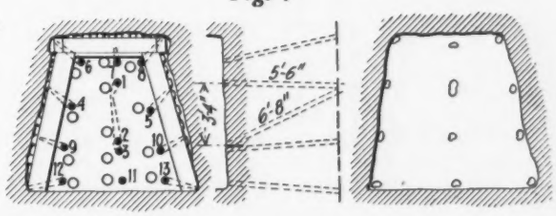


Fig. 4



Standard V-cut rounds used at Copper Queen

Fig. 1 shows a 10-hole standard round, 3 ft. 6 in. deep; circled figures show the powder distribution and the uncircled figures the rotation of firing; powder requirements are 45 sticks of 40 per cent. Fig. 2 shows a 13-hole standard round, 5 ft. 8 in. deep, requiring 75 sticks, 1¼ in., 40 per cent. Fig. 3 is a 16-hole round, 4 ft. deep, using 92 sticks of the same size and grade. Fig. 4 is a 13-hole standard round as commonly drilled in a timbered drift.

ard 5—14 deg. taper, 90 deg. angle wings. The gage of the starter drill is 1¾ in., with a reduction of ⅛ in. in gage for each change.

Each drill has a standard 1-in. lugged Leyner shank and is interchangeable with all types of rock drills in use at that branch or at other branches standardized on that steel section.

At the Old Dominion all major development headings are followed by storage-battery locomotives for handling muck and supplies. Sidings or turnouts are provided at regular intervals for the storage of cars and to avoid long hand trams.

At the Morenci Branch in main extraction and haulage drifts a large-type car is in use, with a capacity of 3 to 5 tons. In other properties, in all ordinary size development drifts, a smaller box-type side- or end-dump car is in general use. All mine cars are equipped with Hyatt roller or Timken bearings. Small cars have chain couplers. The larger cars are equipped with standard M.C.B. couplers.

In sublevel and intermediate work, development faces are served by hand trammers. Trams of 250 ft. or less are usually done by the regular mucking crews. On all longer trams regular carmen or haulage crews are provided to assure a supply of empty cars to the nearest passing track and to remove loaded cars.

Economy in Equipment Usage

(Continued from page 656)

important factor in reducing the quantity of supplies, and on the whole has been very satisfactory. Many supplies are used simply because the user is accustomed to them, and not because something else will not serve the purpose fully as well. Stocks carried for certain purposes will necessarily become obsolete in time, because of changes in flow sheets and equipment, or else no progress will have been made; but such obsolete stock can be kept at a minimum if stocks on hand are kept at a minimum, and can often be used for some other purpose than the one originally intended.

The same policy was carried out at the various branches among their individual departments; such stocks could be obtained without charge to the department that would use them. When no charge is made to another department for such stock it usually disappears quickly. Complete lists of all material salvaged were not kept, but the following list represents the types of materials of major value that are being continually salvaged: Scrap copper, scrap brass, structural steel, sheet steel, lumber, lead, rails and fittings, casing and standard pipe, pipe fittings, cables, shafting, corrugated iron, brick, babbitt, boiler flues, and foundry scrap. To give some idea of the quantity of some of these materials, one branch has salvaged as much as 3,500 tons of foundry scrap, 59 tons of scrap copper and brass, 8,000 lb. babbitt, and 34,000 lb. lead in one year.

When the concentrator at one branch was remodeled three years ago, about 450 tons of steel was used for construction. The only new steel purchased for this job was one 6 x 6 x ½-in. angle, 23 ft. long. The greater part of the reinforcing steel used on this job consisted of used Marathon mill rods. A lime-preparation plant was also built entirely of salvaged material and equipment, with the exception of the housing necessary for the elevator equipment. At another branch a small concentrator was built, the equipment of which was obtained almost entirely from the obsolete equipment discarded at one of the other properties. The greater part of this salvaged material has now been disposed of, one branch reporting that all that it has on hand consists of but a few thousand dollars' worth of structural steel, which has been cut up and segregated and set apart for loading.

Records of the substitution of supplies were not kept, for the figure that was watched was the amount of reduction in the supply stocks; but the following two substitutions in smelter work will serve to illustrate the attempt to reduce purchases: At one smelter no fireclay mortar has been purchased for four years. The use of a mixture of ground silica brickbats and slimes has been found to make a satisfactory mortar for boilers and flues, and for grouting reverberatory arches. Previously, about 500 sacks of fireclay per year were purchased for this purpose. Crushed-slag and cement-concrete hearths have been used to replace all roaster hearths broken during the last five years. Such hearths give satisfactory service and are more quickly installed than the tile hearths.

Salvaging operations serve two major purposes: First, to obtain usable material at a lower cost than what would be paid for new material. Second, to clean up the property. This last-mentioned purpose, although given second position, may be of primary importance, for there is in a neat property a certain psychology that cannot be measured in dollars and cents. It tends to improve safety conditions, and also tends to cause the operators to take more pride in their work. Cars at convenient locations for receiving scrap materials aid in keeping the property cleaned up as well as in furnishing scrap for the foundry. It has been found that about 50 per cent of the scrap required at one foundry is so furnished from operations.

Encouraging an investigation of the slag dump, rather than trips to the supply department, had such an effect on one master mechanic that he announced that he no longer cared if the supply department was kept open or closed. If he could not obtain the material wanted from supplies, he could find something that he could make satisfactory use of from the dump. Such results of course will be obtained more from the effects of observation than from records. It is simply one more phase in the line of conservation of material which is being so generally sought in all branches of business today.

Employees' Benefit Association Functions Admirably

THE Copper Queen Branch Employees' Benefit Association was organized Jan. 1, 1910, for the purpose of providing life, sickness, accident, and disability insurance to the employees of the company, at cost, writes H. C. Henrie, manager of the Labor Department. Membership in the association is voluntary. Membership dues to members are 1.6 per cent of the members' daily wage, based on a maximum of $150 per month. The corporation contributes $10,000 a year to the support of the association.

Members are entitled to the following benefits:

Death Benefit—One year's wage, not to exceed a maximum of $1,500.

Disability From Sickness or Accident Off Duty—One-half members' wage, not to exceed a maximum of $75 per month nor to exceed a disability period of 52 consecutive weeks.

Partial or Permanent Disability—Certain stated amounts are provided for loss of eye, arm, or leg, and for total disability.

The Benefit Association has been popular with the employees, and the percentage of employees becoming members has shown a steady increase each year since the date of its formation. At present 96.9 per cent of all employees, or almost every employee who is eligible to membership in the underground department, are members, and 93.1 per cent of all the eligible employees of the Copper Queen Branch are members.

During the 18½ years the association has been functioning, 21,108 death, sickness, and disability claims, amounting to $1,012,375 in benefits, have been paid to members. During the same period the association has accumulated a surplus and reserve amounting to $88,375.29.

In the period 1921-27, inclusive, the total income of the association was distributed as follows: Death benefits—20 per cent; sickness benefits—40 per cent; accident benefits—12 per cent; operating expense—8 per cent; and surplus and reserve—20 per cent.

The affairs of the association are administered by a board of trustees, one-half of whom are elected by the employees, and the remainder appointed by the Corporation.

Mine Operation

By Joseph P. Hodgson

Manager, Copper Queen Branch

THE orebodies of the Copper Queen Branch of Phelps, Dodge Corporation, in the Warren district of Arizona, are in Paleozoic rock and resulted from the same magma that caused the explosive intrusion of the Sacramento Hill granite porphyry. The ore clusters about the south side of the granite porphyry, and also intrudes along radiating break zones into the limestones for long distances. Ore that was upthrown about 1,500 ft. on the north side by the Dividend Fault has been dissipated by erosion or may in places be covered by Cretaceous rocks.

The orebodies are of three types: (1) The disseminated, secondarily enriched orebodies in granite porphyry, which are characterized by unevenly oxidized tops and assay-bounded bottom and sides; (2) certain bodies in the contact breccia replacing limestone fragments, which bodies are difficult to find, scattered as they are like plums in a pudding; (3) the replacement bodies in the limestone, having a main body, or trunk, and branches and roots. The second and third types vary from fully oxidized orebodies on the west end of the district to primary sulphides on the east.

In virgin ground, prospecting is blind because surface leads are few and give no clew as to horizon. Any block of favorable ground 200 ft. on a side is subject to systematic cutting up by drifts and raises. This, combined with the fact that the limestone orebodies average only about 35 ft. thick, with an average dip of only 20 deg., demands the high ratio of one foot of prospecting to every ten tons of ore extracted.

Experience has taught that systematic development of orebodies, except those of the disseminated type, is not always possible, and development by stoping is in some instances resorted to. The remarkable thing is that, in spite of the handicaps enumerated, mining costs compare favorably with those of other camps.

Mining methods in the Copper Queen mines are divided into three general classes: (1) Selective mining of small, limestone-replacement orebodies containing 2 to 10 per cent copper; (2) block caving of low-grade porphyry orebodies; (3) steam shoveling of low-grade porphyry orebodies. The nature of the limestone orebodies restricts the choice of methods to those in which all ore must be drilled and blasted and delivered to chutes. The orebodies are extremely erratic in size and shape. Irregular distribution of copper content often requires hand sorting. The ground is generally heavy or blocky, necessitating small stope sections closely timbered and filled.

The orebodies are widely separated, both vertically and horizontally. In the respective operations the mining method depends on the size and shape of the deposit, the thoroughness with which overlying ground has been prospected, and the availability of filling material. Irregularities within the individual orebodies often preclude extensive preliminary planning. Stoping methods may differ in the same orebody. The method must always be flexible enough to be adapted to any change encountered.

Table I—Ore Production by Stoping Methods, 1926-27

	Per Cent of Total			
Year	Square Set	Top Slice	Cut and Fill	Miscellaneous
1926.....	52	45	3	..
1927.....	58	35	4	3

The square-set method is used in flat lenses of ore that are irregular in horizontal extent and too thin to permit top slicing. Scrapers and double-drum hoists replace hand shoveling where possible. In narrow deposits of considerable vertical extent the same method may be applied, a large part of the ore sliding by gravity to raises driven from levels below.

The wide, open square-set stopes of the past have been replaced by small sections, seldom over 20 ft. wide. These are mined rapidly, supported by light timber, and closely filled. A typical stope section is shown in Fig. 1.

Underhand square setting has come into use in the Copper Queen during the last few years in mining heavy ground adjacent to old stopes. Where possible, benches from the ore chute are carried on floors below the main working floor, to reduce the amount of hand shoveling. Sometimes the stope may be blasted in floor by floor, becoming in effect a modified top slice. This method has almost overcome difficulty that may develop from side pressure formerly experienced in the overhand square-set stope.

Top-slice methods are applied to all of the larger orebodies in soft ground. The scraper and double-drum hoist replace shoveling when possible. Where practicable, the sub-level heading method, shown in Fig. 2, is used.

As shown in Table I, only 3 to 4 per cent of the ore is sufficiently self-supporting to permit open stopes. Inclined cut and fill or shrinkage stoping is used in this type of ground.

Experience has shown that unit costs can be reduced only by the use of mechanical labor-saving devices, by increasing labor efficiency, by the adoption of the contract and bonus system, and by reducing the cost of supplemental operations such as haulage, supply distribution, hoisting, ventilation, and drainage.

The Copper Queen miner is necessarily of the old-time all-around type, there being no division of labor by classes of work. The miner does the drilling, timbering, shoveling, repairs, short trams to chutes, and such other work as may arise in his working place. Stopes are divided into as many sections as is practicable, with one or two men per section on each shift. The small crews, with the incentive offered by the contract and bonus system, show a relatively high efficiency.

By means of long ore passes, the bulk of the haulage is concentrated on two levels. Loading chutes are provided with overhead platforms and double arc-type gates, the relative positions of which depend upon the amount of moisture in the ore. Rapid loading is accomplished by using five-gate chutes, which permit spotting two or three cars at one time. The complexity of the transportation problem is shown by the fact that at the beginning of 1928, 1,200 tons daily production from the Limestone Division required 83 haulage or transfer chutes and 30,000 ft. of track.

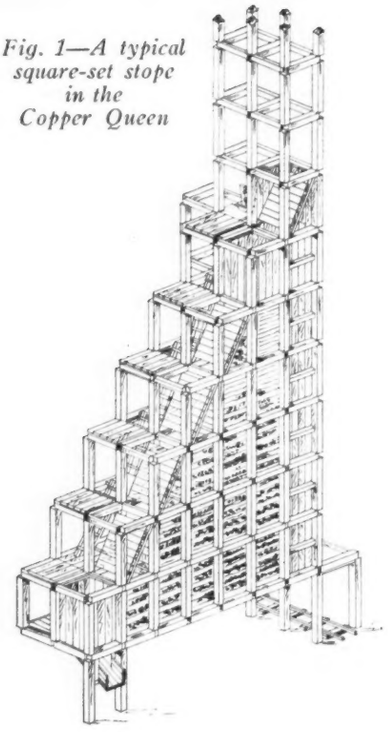


Fig. 1—A typical square-set stope in the Copper Queen

The distribution of supplies, now in charge of a supply foreman, is an important item on the cost sheet. Timber yards, drill-steel shop, drill-repair shop, and tool houses are provided at the collar of a centrally situated supply shaft. By means of a specially designed truck that can be swung into the cages, material up to 10 ft. long can be loaded in the timber yards or shops and transported, without rehandling, to the underground supply stations in important mining areas. Under this system the number of men on supply distribution has been reduced almost 50 per cent.

The Copper Queen porphyry orebodies differ from the general type of porphyry ore mined by block caving in that they are quite aluminous, often contain much water, and that the copper content is erratic in distribution. When wet, the ore has a tendency to pack in the stope, following undercutting, and in chutes, cars, and skips in which it is handled after drawing.

Block caving was started in April, 1925, and is now emerging from the experimental stage. At the beginning, the Morenci inclined-slide method was tried, with a drawing height of 50 ft. This was later abandoned in favor of undercutting over finger raises. The height of the column of ore was increased in successive lifts to 75 ft., and then to 125 ft. As shown in Fig. 3, the full height of one orebody (240 ft.) will be drawn in the latest block under development. Hand tramming will be avoided in this plan.

Table II—Productive Efficiency in Stoping and Development Operations, 1927-28

	Stoping, Tons per Man-Shift		Development, Feet per Man-Shift	
	Limestone	Porphyry	Drifts	Raises
1927	4.90	17.98	1.47	0.83
1928 to date	5.30	19.50	1.62	1.00

Steam-shoveling operations, started in 1918, will cease early in 1929, by which time the open pit will have reached a depth at which the ore can be mined more cheaply by glory-holing and underground haulage. In addition to lower mining cost, the glory-hole method will permit leaving in the walls of the pit a large volume of waste that would otherwise have to be excavated to make room for steam-shovel operations. The change to the glory-hole method will be made without interrupting production. Fig. 4 shows the glory-hole method now under development.

Leaching operations during 1928 have assumed an important position in copper production. The capacity of the main cementation plant has been increased from 750,000 to 1,000,000 lb. per month. This plant treats the liquors obtained by leaching surface heaps of low-grade stripping material from Sacramento pit operations. A smaller plant has been erected near the Holbrook mine to recover the copper in water pumped from the mine after percolation through old sulphide stoping areas. This plant has a capacity of 100,000 lb. per month.

Moctezuma Copper Company

The Moctezuma orebodies, as shown in Fig. 5, are scattered along the perimeter of and through a mineralized zone, which is in the shape of a cylindroid, elliptical in outline in the horizontal plane. Within the oval the rocks consist of latite breccia from the surface to a point between the 900 and 1,000 levels, and of andesite breccia below this point. The rocks outside of the oval are latite breccia to the 300 level, underlain by monzonite. Ore distribution was probably governed by several major faults that cut through the deposit. The principal copper mineral is chalcopyrite, mixed with varying amounts of pyrite. As a whole, the ore is medium to low grade, averaging about 2.60 per cent copper.

The mining method employed depends upon the size and shape of the orebody, the grade of the ore, the quantity of waste mixed with the ore, and the character of the wall rock.

Table III—Ore Production by Stoping Methods, 1927

Method	Per Cent of Total
Horizontal cut and fill	58.6
Incline cut and fill	15.7
Shrinkage and fill	14.4
Other methods	11.3
	100.0

The ore generally supports itself well, but owing to the necessity for selective mining, weak waste walls, and flexibility necessary to meet the irregularities in size and shape of orebodies, the horizontal cut-and-fill method predominates. After completion of level gangways and of silling out on the level or at the bottom of the ore, each successive cut (8 ft. thick) is followed by close filling obtained through waste raises spaced at 50-ft. intervals along the longest dimension of the stope. Production from the section is continuous. Waste is spread by the type of buggies used for concrete. Ore chutes and manways are spaced 30 ft. apart and are built up through the fill as the stope advances. Hand sorting is the practice in all horizontal cut-and-fill stopes.

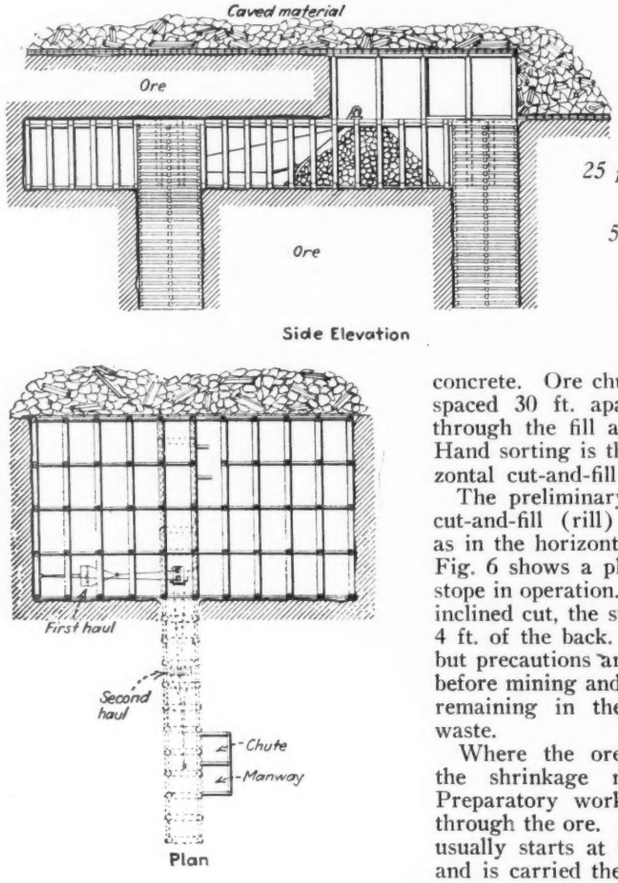


Fig. 2—Subheading top-slice mining at Copper Queen

25 per cent slides directly to chute

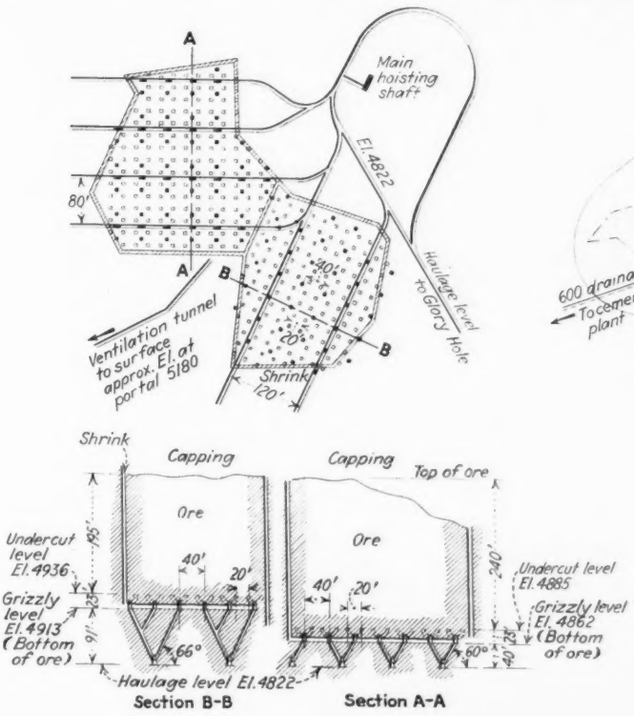
55 per cent requires one pull

20 per cent requires two pulls

The preliminary work in the incline cut-and-fill (rill) method is the same as in the horizontal cut-and-fill method. Fig. 6 shows a plan and section of the stope in operation. After taking an 8-ft. inclined cut, the stope is filled to within 4 ft. of the back. No flooring is used, but precautions are taken to wet the fill before mining and to scrape the fine ore remaining in the stope down to the waste.

Where the orebodies are amenable, the shrinkage method is employed. Preparatory work starts with a raise through the ore. From the raise, silling usually starts at the bottom of the ore and is carried the full width of the ore

body. Grizzly drifts are driven 50 ft. apart and 20 ft. below the bottom of the stope. From the grizzly drifts, inclined draw raises at 25-ft. intervals are driven to the stoping floor. These discharge into branches of main-haulage raises. In large stopes, 15-ft. pillars may be left, to be undercut and mined near the end of stoping operations. Stopes are filled with waste after drawing is complete.



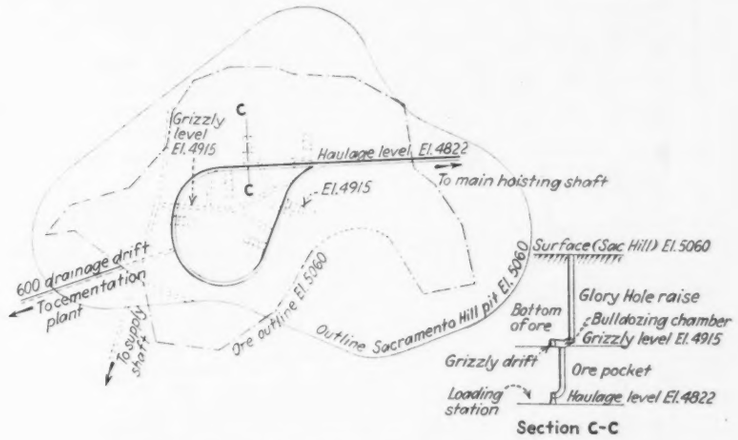


Fig. 3, to the left, shows a diagram of block caving on the north block of the east orebody. Fig. 4, above, shows glory-hole development for Sacramento pit

Table IV—Stoping Data for 1927

	Pounds Powder per Ton	Feet of Timber	Tons per Man-Shift
Horizontal cut and fill..	0.42	2.51	4.26
Rill.....	0.41	1.59	5.25
Shrinkage.....	0.15	1.0	12.41

Waste for stope filling, quarried on the surface and after being broken up in bulldozing chambers, is delivered through raises to the mine levels. Tramming is done by hand and electric power. In hand tramming, 22-cu.ft. end-lump cars are used; and 22- and 33-cu.ft. rocker side-dump cars for motor haulage. The contract system applies to almost all underground work. Contracts are divided into three classes: stoping, development, and miscellaneous.

Morenci Branch

At present, the output at Morenci all comes from the Humboldt mine and is produced by one system of mining—the Morenci block cave. The Morenci timbered-slide method is reserved for the softer ores, where lifts of more than 100 ft. are not available. This method was described in *Engineering and Mining Journal-Press* in an article on "Mining Methods at Morenci," issue of Dec. 26, 1925, and few changes have been made since.

Morenci ore deposits are typical of secondary enrichment, but it is generally conceded that they are harder than those in other mines of the Southwest using block-caving methods. The geology is faithfully described in that classic of the U. S. Geological Survey, Lindgren's Professional Paper No. 43. Ore reserves of the higher grade average less than 2 per cent copper and lie principally in one mass along two intersecting fault zones, through a maximum length of 2,000 ft., a width of 600 ft., and a vertical range of 1,000 ft.

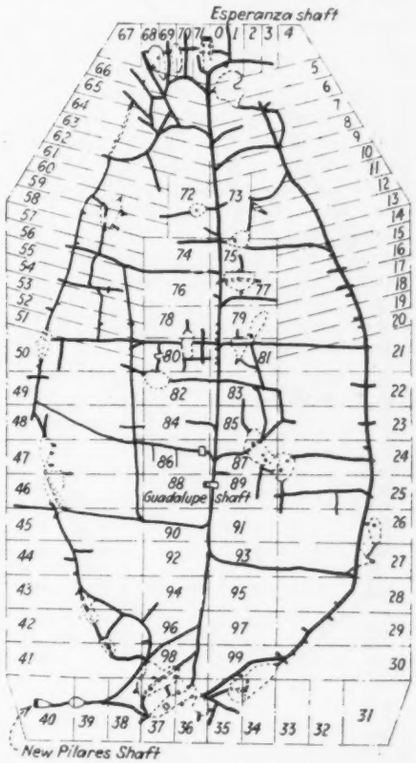
The Morenci block-caving system of mining was developed at Morenci, by actually testing several of the recognized standard methods of caving that seemed best adapted to Morenci conditions, and later by introducing changes in development layouts and stoping plans to meet local requirements.

The present standard method is shown in the plan and section, Fig. 7. A stoping panel is 112 ft. wide, and is served by two haulage drifts on 56-ft. centers. Double haulage chutes are established along these drifts on 28-ft. centers, because the 10-ton cars used in ore haulage couple on 14-ft. centers (Fig. 8). These chutes are raised to an elevation of 50 ft., where grizzly drifts are run at right angles to the haulage drifts. These raises are driven on a 75-deg. inclination. Alternate raises are slotted for 7 ft. below the grizzly level, to accommodate two grizzlies on 14-ft. centers (see Fig. 9). This arrangement makes the grizzly interval along the grizzly drift either 14 or 21 ft. Two opposite fingers are run from each grizzly to an elevation of 20 ft., to the undercutting level. By inclining these fingers in a plane parallel to the direction of the grizzly drifts, their spacing on the undercutting level is uniformly $18\frac{2}{3}$ ft. in one direction and 14 ft. in the other.

Boundary-shrinkage stopes about 6 ft. wide are silled on the undercutting level and carried up as high as may be necessary to cut off from the surrounding territory the block to be caved. Vertical pilot raises, driven in advance of the stope-silling operation, on a horizontal interval of about 140 ft., serve as entrances for men and supplies (see Fig. 10). These connect with an intermediate supply and observation level, 90 ft. above the grizzly level, and, when necessary, continue to a level at the top of the ore, at a total height of 200 ft.

After the first section of the boundary shrink is completed, horizontal undercutting is accomplished by the "checkerboard" method. Longitudinal drifts,

Fig. 5—The Moctezuma orebodies



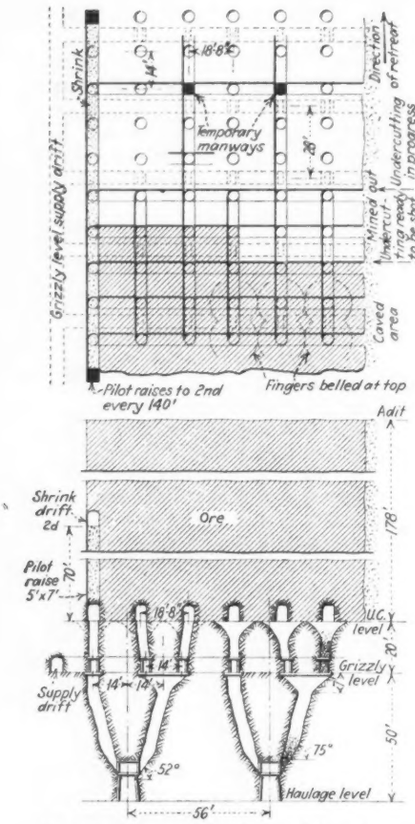


Fig. 7—Standard Morenci block-cave mining method

4x6 ft. in cross-section, are run on the undercutting level, directly over alternate rows of fingers, to the end of the block to be undercut, an initial crosscut over the entire width of the panel having first been driven, in which temporary manways are constructed from the grizzly level. Then, retreating from the end of the block, small crosscuts are extended over each row of fingers, and the stub ends of the remaining longitudinal drifts are connected (see Fig. 7). Intervening pillars are blasted out. The tops of the fingers are belled out. The backs of the drifts and crosscuts are drilled to an additional height of 6 ft., and this "cut" is shot with the pillars to provide room for expansion. Adoption of the "checker-board" system has the advantage of insuring thorough undercutting. It permits immediate inspection, is elastic (as pillars may be blasted when necessary), permits of good ventilation, and is safe.

It is important that the last line of pillars shot down be not drawn for a few days, until the remainder of the block is in good drawing condition. This prevents excessive weight being transmitted ahead of the block just undercut, which would damage the advance-stope preparation work. Grizzly openings, formerly 10 in., have been widened to 16 in., thereby increasing chute-tapping efficiency from 37 tons to 108 tons per man-shift. Drawing-off operations are controlled by the Engineering Department, which also keeps permanent records of production and grade. Drawing is stopped when a definite minimum per cent total copper is reached.

The stope panel is narrower than formerly, to avoid the extreme weight that developed in the center of the wider panel previously used. To maintain the required daily output, the productive area had to be lengthened. This benefits the transportation, as less switching in the stopes is required. Originally the angle of draw averaged about 60 deg. With the present narrow stopes, it averages about 20 deg. This change has reduced dilution, which to date, on 3,713,025 tons mined since the change, is less than 5 per cent. The mine is well ventilated by two Sturtevant exhaust fans, each of 100,000-cu.ft. capacity, on opposite ends of the orebody.

Tramming is by electric haulage. Mine cars are of 10-ton capacity, and from 20 to 25 cars are hauled in a train. The average length of haul is about 2,500 ft. By reason of the large capacity of cars and trains, haulage costs are very low. As manager of the Morenci Branch from 1918 to July, 1927, I feel a personal pride in the excellent results accomplished through the co-operation of the staff.

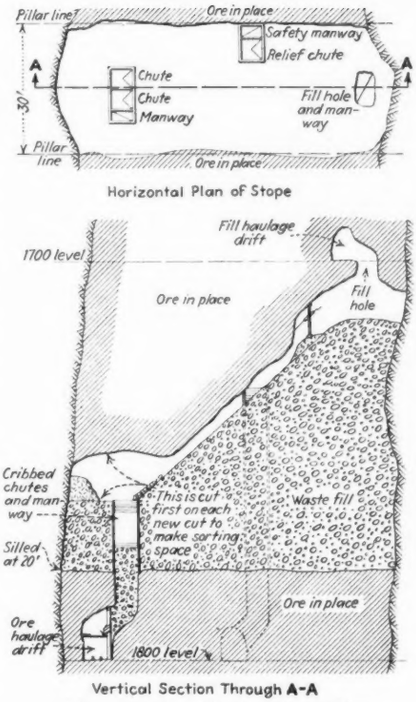
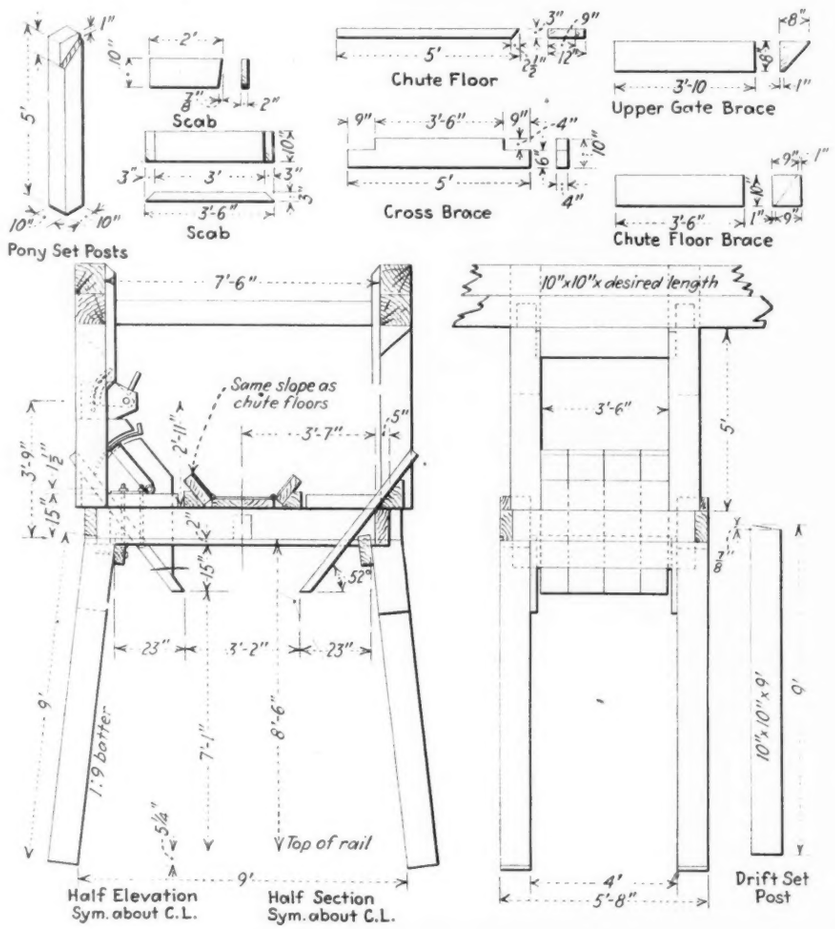


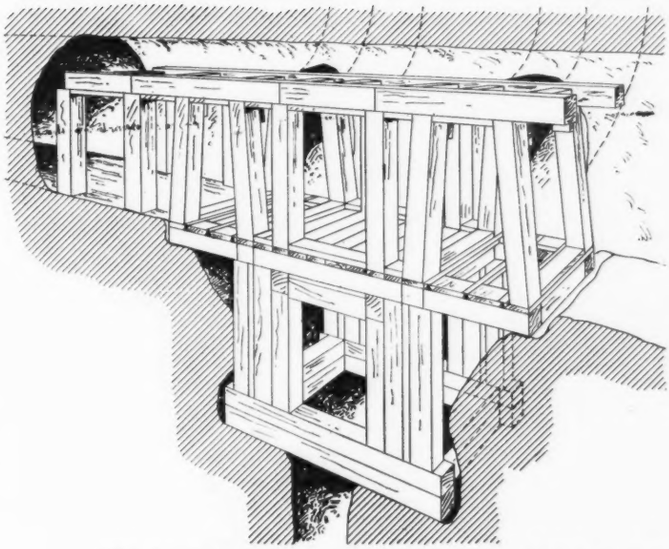
Fig. 6—A typical rill section

Fig. 8, right—Chute fronts, 10 x 10-in. sets

Timber Schedule

Number	Amount	Size
201	4	10" x 10" x 9' 0"
116	4	10" x 10" x 5' 0"
112	2	10" x 10" x 8' 0"
104	2	10" x 10" x 3' 6"
79	2	8" x 8" x 3' 10"
19	2	4" x 10" x 5' 0"
61	1	6" x 8" x 4' 0"
293	2	6" x 8" x 7' 0"
225	2	4" x 10" x 5' 0"
128	2	2" x 10" x 7' 0"
22	4	3" x 10" x 3' 4"
21	4	5" x 10" x 2' 0"
9	4	2" x 10" x 2' 0"
10	4	3" x 10" x 3' 6"
117	4	3" x 9" x 5' 0"
118	4	3" x 12" x 5' 0"
208	4	3" x 10" x 5' 0"
13	2	5" x 12" x 4' 0"





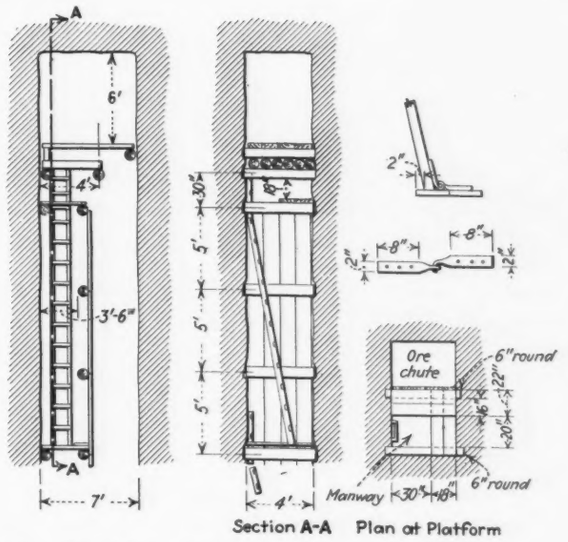


Fig. 9—Grizzly station in a Morenci stope is shown at the left. Fig. 10, on the right, shows a standard manway stull raise

Table V—Annual Progress of the Morenci Block-Caving Systems

Year	Tons Mined	Per Cent of Total Stoping	Bd. Ft. Timber per Ton	Pounds Powder per Ton	Tons per Man-Shift on Stoping
1924	125,743	13.32	1.60	0.54	12.39
1925	616,074	45.82	0.81	0.35	22.33
1926	1,112,299	78.72	1.22	0.23	28.99
1927	1,136,339	63.96	0.23	0.24	40.35

Old Dominion Company

The Old Dominion vein is a true fissure vein, varying in dip from 45 deg. to vertical and in width from 3 to 60 ft. Several outside veins are mined, which range in dip from 35 deg. to vertical. On the west side, the oxidized orebodies lie in rather flat tabular deposits.

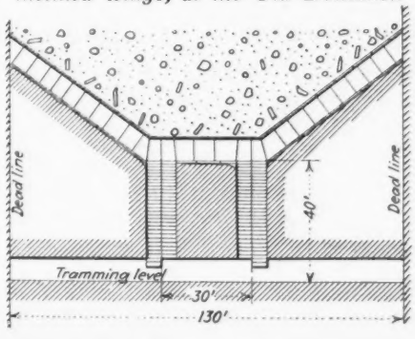
The major portion of mining is done in a section of the vein averaging about 65 deg. in dip. Nearly all this area has a diabase hanging wall, which is intensely altered and caves very easily. The wide variation in dip and the lack of uniformity in wall rock make it impossible to adopt any particular mining method throughout the mine. A description of each major mining method, with the facts of occurrence that have determined the choice, follows:

Square Setting—The distribution of oxidized ore on the west side is very erratic. It is impossible to delimit ore at the start of mining, so square setting is resorted to wholly. The ore on the extreme west side is overlain by a flatly west-dipping flow of dacite, which is covered with the water-filled Gila conglomerate. This ground must be square-setted and filled, to prevent any caving and fracturing in the dacite, which would permit a flow of water through it. In this section of the mine the square sets toward the hanging wall are carried up in advance of those toward the footwall. This permits placing temporary slides in the square sets, so that the ore will flow to the drawing raises by gravity; and, in like manner, by the proper placing of gob raises, the greater part of the stope can be filled by gravity. This system has the further advantage that the hanging wall, which is rather flat, will be caught up early in the stoping operations.

Top Slicing—Where the vein is steep and the ore is sufficiently high grade (3 per cent and up), top slicing is used. If there is sufficient vertical height (50 ft. or more) inclined top slicing is used; otherwise flat top slicing. Where inclined top slicing is applicable, it has been found advantageous from the standpoint of safety to combine short, flat slices and inclined wings (see Fig. 11). This insures an exit for the men if there is a run of dirt in either wing.

Modified Morenci Slide Method—Some narrow, low-grade sections of the Old Dominion vein can be mined profitably by a method that avoids the use of timber and fill. These sections are too flat to permit shrinking from one level to another (100 ft.), so an intermediate Morenci slide is driven at 50 ft. above the level, parallel to the vein and on the footwall. The slides are apexed 25 ft. from raises driven at 50-ft. centers. Shrinking is then done over the slides in the same manner as over a drift, Fig. 12, in which hanging wall No. 1 represents the condition of a narrow vein just described. Here, shrinking is carried above the inclined slides along the footwall, and the ore, drawn through controls in each set of the incline, flows by gravity to the raises.

Fig. 11—Short flat slices combined with inclined wings, at the Old Dominion



The California vein is so flat (35 to 40 deg.) that cribbed raises do not serve effectively for ore disposal. In this instance Morenci slides are driven up the dip and at right angles to the strike to the top of the ore. Usually 20-ft. pillars are left between these slides. Mining then starts at the top. As the retreat is made, rows of stulls from footwall to hanging wall are put in, and a lace of lagging is thrown behind them to protect the men below from sloughing ground. This method permits the salvaging of timber.

Caving—On the 2,200 level west, a body of low-grade ore was developed with a maximum width of 80 ft., a maximum vertical extent of 120 ft., and a length of 150 ft. The estimated tonnage in this section was about 40,000 tons. A caving installation using Morenci slides was employed. Results will be discussed later.

An adaptation of the Morenci-slide caving method is successfully used on the vein where the dip is about 60 deg., the width 25 ft. or more, and the grade too low to permit mining by another system, or where the ground is badly broken up (see Fig. 12, hanging wall No. 2, and Fig. 13). Referring to Fig. 12, hanging wall No. 2, the cross slides are driven to the hanging wall at 20-ft. centers, and a narrow shrink is carried up along the footwall. The remaining ore toward the hanging wall is then caved and drawn through controls in the cross slides.

Referring to Fig. 13, a flat pony drift is driven along the footwall, at the proper elevation, connecting with raises spaced so that slots from these raises will receive the ore from the cross slides. This method has the decided advantage that the drawing elevation of corresponding points in the slides is the

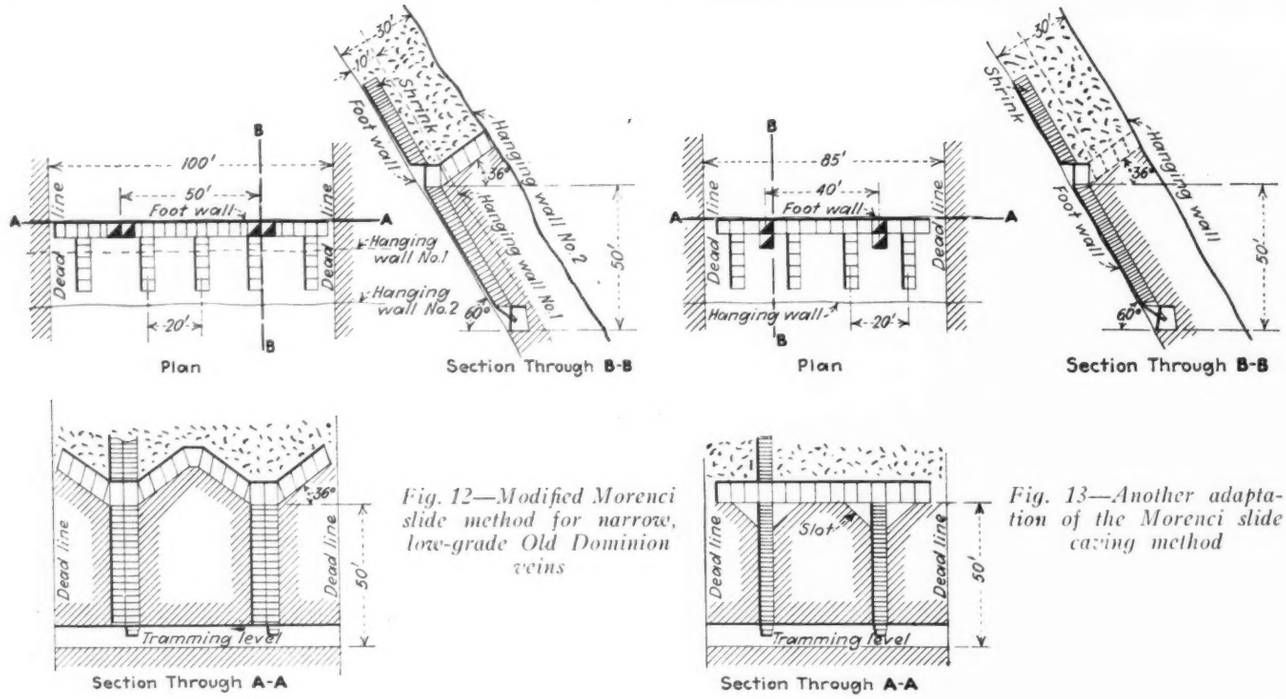


Fig. 12—Modified Morenci slide method for narrow, low-grade Old Dominion veins

Fig. 13—Another adaptation of the Morenci slide caving method

Table VI—Stoping Results, May 1, 1927, to May 1, 1928

	Wet Tons per Man-Shift	Cost per Wet Ton—Labor	Timber	Powder	Total
Stope development	2.24	$2.22	$0.77	$0.34	$3.33
Stoping	26.26	.19	.003	.04	.23
Total	16.97	.29	.04	.06	.39

same, thus giving an even distribution of weight on the timber installation. This method is now being used almost exclusively. All of these areas have been so well developed that it is possible to make close estimates. Without exception, the full tonnage has been drawn, with, of course, a drop in grade resulting from hanging-wall dilution.

Efficiency—Referring back to the caving stope on the 2,200-level west, the stoping results obtained from May 1, 1927, to May 1, 1928, are shown in Table VI.

Estimated tonnage was 40,489 tons at 2.2 per cent. The actual tonage drawn was 56,829 wet tons, or about 40 per cent overdraw. The average grade was 2.24 per cent.

With the introduction of the Morenci slide, with its various applications as described above, an immediate increase in efficiency was observed. The introduction of these slides was started during the last six months of 1927. Their use has been gradually increased to a point where about 45 per cent of the stoping is done by one of these methods.

Table VII shows the tons per man-shift, total stoping, from Jan. 1, 1927, to June 1, 1928:

Table VII—Tons Per Man-Shift, Total Stoping

Period	Average Tons per Man-Shift
First six months 1927	5.94
Second six months 1927	7.34
First five months 1928	10.12

The stoping cost, including labor, timber, and powder, has been reduced from about $1.25 per ton to $0.65 per ton.

I am indebted to the mine superintendents of the Copper Queen Branch, Morenci Branch, Old Dominion Company, and the Moctezuma Copper Company, and to their mine departments, for the preparation of much of the data contained in this article.

Vacuum Plays Important Part in Concentrate Dewatering

CONCENTRATE products at Morenci consist of a concentrate obtained from roughing-table operations, the ore having been crushed to about 7 mesh, and a concentrate produced by two-stage flotation, on 48-mesh grinding in the first stage, and 65-mesh grinding in the second stage, according to Dale C. Barnard, assistant concentrator superintendent.

Table concentrate, carrying 87 per cent water, is laundered to dewatering Dorr classifiers equipped with 4 ft. 6 in. vacuum drainage. The coarse product then is treated in a second Dorr classifier, equipped throughout its entire length of bottom with vacuum drainage. Final product from the classifiers carries an average of 8 per cent moisture, and is loaded into cars by a 20-in. belt conveyor.

The cycle of operation on the vacuum classifiers is 1 min. suction, followed by 15 sec. blow. Air used for blow is obtained from flotation air mains at 1½ lb. pressure. The overflow of the primary classifiers is settled in tanks with the fine material in air flotation concentrate, as noted below.

The flotation concentrate from final cleaner cells, at an average of 70 per cent moisture, is thickened in two 30-ft. Dorr thickeners with tank bottoms and rakes set at 37 deg. from the horizontal. These two tanks allow 6.87 sq.ft. of thickener capacity per ton of concentrate handled. The overflow, which contains finely divided solids, is sent to a 60-ft. tank for settling. The spigot or thickened product carried an average of 20 per cent moisture and is piped direct to Oliver filters, the product carrying an average of 11 per cent moisture. Flotation concentrate from the Oliver filters drops onto the bed of table concentrate on the conveyor, and the conveyor system delivers direct to railroad cars. Two breaks in the conveyor system provide means of mixing the two products before loading into cars. A moisture loss of about 1 per cent occurs in the 7-mile railroad haul between concentrator and smelter.

Copper Queen Hotel Meets Needs of Traveling Public

FOLLOWING the beginning of mining in the Warren district of Arizona, and the subsequent rapid expansion of operations, the need developed for a suitable hotel to accommodate visitors. The Phelps Dodge Corporation therefore planned and erected at Bisbee, in 1901, the Copper Queen Hotel. It was remodeled in 1927, and made one of the most modern hotels in the Southwest, containing 54 guest rooms and adequate dining-room facilities. An average of 40 persons patronize the hotel daily.

Concentration Trends

By W. B. Cramer

Consulting Engineer, Concentrating Department

THE LAST decade, constituting the post-war period, has been indicative of marked progress in all branches of mineral production. Within this period considerable advance resulted in concentration practice by reason of the growing importance and use of the flotation process; the development of selective flotation, with consequent simplicity of flow sheet; the discovery of new, more efficient, and cheaper reagents for use in flotation; and the development of new and improved equipment for crushing, grinding, and classification.

Development of modern methods of concentrating copper ores as practiced by Phelps Dodge Corporation was initiated in 1918. In anticipation of the treatment by concentration of the Sacramento Hill West orebody at Bisbee, and with the desire to improve metallurgy in the concentrators of the other branch plants, pilot plants were constructed and operated between 1918 and 1920 at Bisbee and Nacozari under the direction of H. Kenyon Burch, then consulting engineer of the Concentrating Department of the Phelps Dodge Corporation. Operation of these pilot plants covered the treatment of ore from the Pilares mine in the Nacozari pilot plant; and ores from the Copper Queen West orebody, the Old Dominion Company, and the Morenci Branch in the pilot plant at Bisbee. Step concentration was used in the design and operation of these pilot plants, and this included flotation as an intermediate process between roughing and finishing tables, and marked, in the operation of Phelps Dodge, the advent of flotation as a major process. Previous to this, flotation had been used at the several branch plants as a minor and scavenger process, following the use of gravity processes for recovering a large proportion of the mineral content.

Step concentration was adopted in pilot-plant design by reason of ore characteristics which made it unnecessary to fine-grind the ore for the purpose of separating mineral from gangue; also by reason of the desire for a large proportion of coarse concentrates for subsequent smelting operations and the desire for pyrite for smelter fluxing of siliceous copper ores. The proposal to use only flotation and finishing tables in the treatment of the West orebody at Bisbee was negatived, because the scheme involved the production of excessively fine material for subsequent smelting and of a grade no higher than would be obtained by step concentration.

Based on the results of pilot-plant operation, it was decided to remodel the Nacozari concentrator and to construct a 4,000-ton concentrator at Bisbee, the flow sheets of which were to follow those of the pilot plants, with the use of flotation as an intermediate process between roughing and finishing tables. The remodeled Nacozari concentrator started operations in June, 1922, and the newly constructed Bisbee concentrator in April, 1923. The original flow sheets of these concentrators were almost identical, and are shown in an accompanying article on selective flotation, by W. T. MacDonald, mill superintendent of the Nacozari concentrator. Of special interest in these concentrators was the use for the first time of larger-sized rod mills in the two-stage grinding circuits. Primary single-pass rod mills were used for reduction from 1¼ or 1½-in. material to 14 mesh, the product from which was treated on roughing tables. Secondary closed-circuit rod mills were used for the reduction of 14-mesh material, contained in the deslimed roughing table tails, to a 48-mesh product in flotation. Marcy roller mills were adopted as standard equipment at these concentrators, following the development of this type of grinding mill of large size by Frank Marcy at Nacozari in 1919 with the assistance of the Corporation's concentrating staff. As pioneers in the partial development of the use of smaller-sized rod mills of the Marathon type at Morenci and Tyrone in previous years, the Corporation looked with favor on the proposal to develop larger-sized rod mills of improved mechanical design.

Early operation of these concentrators indicated the desirability of a removal of more pyrite and insoluble, in view of the growing depletion of siliceous copper ores from the Copper Queen mines. The economic benefits to be derived by the production of a higher-grade concentrate by making this change would result from a saving in freight on concentrate shipments, reduction in smelting costs on a smaller tonnage of concentrates, and a reduction in smelter-slag losses owing to the partial removal of slag-forming constituents. In concentration these steps involved: eliminating all gravity processes and thus using flotation as the sole major process; sufficiently fine grinding not only to separate mineral from gangue but also sufficiently fine to separate the copper minerals from pyrite; changes in

Table I—Comparative Equipment Requirements

	The Moctezuma Copper Company		The Copper Queen Branch	
	Original Flow Sheet	Present Flow Sheet	Original Flow Sheet	Present Flow Sheet
1	6 Primary roller mills 17.5 r.p.m. Feed 1½ in.	6 ft. 6 in.x12 ft. 3 in. Discharge, 14 mesh	8 Primary roller mills, 6 ft. 6 in.x12 ft. 3 in.; 17.5 r.p.m. Feed 1½ in. Discharge, 14 mesh	
2	3 Desliming classifiers 6 ft.x20 ft.	.....	4 Desliming classifiers 6 ft.x 18 ft.	8 Dorr Bowl type classifiers 15 ft. bowl diam.
3	36 Plat-O roughing tables	.....	40 Plat-O roughing tables	.....
4	6 Dewatering classifiers, 4 ft. 6 in.x18 ft. 4 in.	.....	8 Dewatering classifiers 4 ft. 6 in.x18 ft. 4 in.	.....
5	6 Secondary roller mills 6 ft. 6 in.x12 ft. 3 in. 17.5 r.p.m. Feed 14 mesh.	Product 48 mesh	8 Secondary roller mills 6 ft.6 in.x12 ft. 3 in. 17.5 r.p.m. Feed 14 mesh	Product 65 mesh
6	6 Circulating classifiers, 6 ft.x23 ft. 4 in.		Product 48 mesh	
7	6 Callow-Inspiration Flotation roughers 1,512 sq.ft.	18 MacIntosh roughers	8 Circulating classifiers 6 ft.x23 ft. 4 in.	
8	6 Flotation cleaners 504 sq.ft.	12 MacIntosh cleaners and recleaners	8 Callow-Inspiration flotation roughers 1,764 sq.ft.	8 Forrester combination cleaner and roughers
9	60 Plat-O finishing tables	.....	8 Flotation cleaners 588 sq.ft.	.....
10	4 Concentrate Dorr thickeners 49 ft. diam. 2 Ditto — 60 ft. diam.	2 concentrate thickeners, 60 ft. diam.	80 Plat-O finishing tables	.....
11	4 Filters, 2–14 ft.x14 ft., 2–12 ft.x12 t.	1 Filter, 14 ft.x14 ft.	6 Concentrate Dorr thickeners, 75 ft. diam., tray tank type	2 Concentrate thickeners 75-ft. tray type
			5 Filters 14 ft.x14 ft.	2 Filters 14 ft.x14 ft.

Table II—Tonnages, Concentrate Assays, and Ratios of Concentration

	Dry Tons Feed	Tons Concts. Produced	Assays, Per Cent Cu	Insol.	Fe	Ratio of Concentration
1924	2,210,150	406,990	10.53	20.97	30.96	5.43
1925	2,108,021	301,721	13.58	7.66	35.50	6.99
1926	2,084,475	277,361	13.51	8.28	34.97	7.52
1927	2,063,068	208,908	18.07	8.50	31.98	9.88
1928 (6 mo.)	1,022,996	116,634	18.92	8.00	32.36	8.77

the flotation flow sheet, and arrangement of roughers, cleaners, and recleaners; and changes in the character and amounts of flotation reagents, including lime.

The effects of selectivity and insoluble elimination are reflected in many concentrator improvements. A marked reduction is noticeable in the amount and character of equipment in active use, as compared with that originally installed in the Nacozari and Bisbee concentrators. Not only does this apply to process equipment in concentrators proper, but also to supplementary equipment, especially thickening and filtering apparatus. This is shown in Table I.

Metallurgically, the grade of concentrate is becoming consistently higher from year to year, ratios of concentration are higher, and insoluble assays are considerably lower than formerly, as indicated by Table II for the Bisbee and Nacozari concentrators.

Owing largely to the elimination of gravity processes; the use of improved reagents, especially xanthate, in flotation; and the successful development and present use at all branch plants of improved flotation apparatus of the MacIntosh and Forrester types, direct costs of operation are gradually being reduced. Relatively less progress has resulted in the lowering of crushing and grinding costs, which at this time constitute about 50 per cent of the total direct expense.

The effects of selectivity and simplicity of flow sheet are of interest when considered with the "concentrate distribution" in the original flow sheet, which shows the recoveries of concentrates and copper made by the gravity and flotation processes, as compared with those at present when using an all-flotation flow sheet (Bisbee and Nacozari concentrators).

The development and present use of chemicals of the type of xanthate have had a marked effect in improvements in the process. There has been a constant trend to the use of a very small amount of reagents—chemicals as collectors and oils as frothers, and which is shown in Table VI, for the Bisbee and Nacozari concentrators.

The use of flotation apparatus of the MacIntosh and Forrester types has had a marked effect in reducing power used in flotation. At present, flotation power constitutes less than 1 kw.-hr. per dry ton of original feed, in contrast with the former consumption of over 3 kw.-hr. for this work. Flotation power originally consumed approximately 22 per cent of the original concentrator power input, in contrast to the present consumption by flotation of slightly over 6 per cent of the total concentrator power.

Substantial reductions have resulted in labor requirements because of simplified flow sheets, consequent elimination of equipment formerly required, and the development and present use of improved flotation apparatus. This, in turn, has resulted in a gradual and consistent increase in tonnages concentrated per man-shift, as is shown in Table VIII.

Phelps Dodge trends have been and are a continuation of simplicity of flow sheet, finer grinding, improved classification, and improved flotation work. Since the starting of the present concentrators, no changes have been made in crushing-plant equipment, and a product is delivered to primary mills considerably coarser than in many other copper concentrators. With the exception of Bisbee operations, already characterized by very fine grinding to the extent that flotation feed contains approximately 75 per cent by weight of minus 200-mesh material, finer grinding than is now being done may be warranted at the other branch plants, with the objective of lower tailing losses. The ore from the lower depths of the mines is harder. This problem of finer grinding is now receiving major attention.

At Morenci, where it is desirable to secure 65-mesh grinding in the secondary grinding circuit, which is equivalent to about 74 per cent of minus-200-mesh material by weight, advantage has been taken of Copper Queen experience in the use of Dorr bowl classifiers for the production of this very fine material.

To accomplish very fine grinding at the Copper Queen preliminary to partial selectivity, it has been demonstrated that the chalcocite and pyrite content of the flotation feed must be largely minus 200-mesh, owing to intimate association of the two minerals. The use of Dorr duplex classifiers could not be expected to give, and did not give under Bisbee conditions of operation, the fine product desired. This led to the experimental installation of two 15-ft. bowl-type classifiers, which has been followed by a completed installation of six additional classifiers of this type and size. These bowl classifiers act as deslimers in the two-stage grinding flow sheet and deslime the product of the single-pass primary rod mills. In this way a clean sand feed, with a minimum content of already finished material, is sent to the lower closed-circuit mills for regrinding to the desired size. The use of bowl-type classifiers also aids in maintaining minimum dilution of flotation feed.

Rod mills have been adopted as standard equipment at Bisbee and Nacozari. As originally installed, the objective was 48 mesh. The change at Bisbee to very fine grinding, to accomplish partial selectivity, and the present trend at Nacozari to finer grinding, have presented new grinding problems. Power and steel consumptions in the secondary closed-circuit rod mills have materially increased, owing to finer grinding. This has led to a recent investigation at Bisbee into the relative merits of rods and balls for use in the lower closed-circuit mills. No changes have been made in primary rod-mill operation. It is possible that the operation of primary mills may be improved by the installation of classifiers to operate in partial closed circuit therewith, and experiments in the effects produced may be undertaken in the near future. Apart from mill grinding, primary rod mills serve efficiently to pre-treat or condition the mill feed with reagents, such as lime, where long and intimate contact is desirable.

The development within the Corporation and the Old Dominion company of new flotation apparatus of the MacIntosh and Forrester types constitutes a recent major accomplishment. By the

Table III—Concentrating Costs—Phelps Dodge Concentrators

	1923	1924	1925	1926	1927	1928, 5 Months
Crushing	$0.089	$0.079	$0.082	$0.081	$0.083	$0.084
Grinding	.250	.220	.204	.188	.200	.189
Flotation	.260	.217	.150	.133	.095	.088
Concentrate handling	.035	.029	.025	.021	.020	.019
Tailings disposal	.034	.047	.028	.018	.022	.021
Water	.080	.076	.079	.069	.063	.060
Miscellaneous direct	.116	.087	.090	.074	.077	.067
Direct cost	$0.864	$0.755	$0.658	$0.584	$0.560	$0.528

Table IV—Concentrate Distribution—Per Cent of Total

	Roughing Tables Weight	Roughing Tables Copper Content	Flotation Weight	Flotation Copper Content
1923	47.20	28.34	46.15	70.55
1924	40.39	18.90	57.62	80.34
1925	1.49	0.64	98.51	99.36
1926 and since	.....	.....	100.00	100.00

Table V—Percentage of Concentrator Feed Copper Recovered by—

	Roughing Tables	Flotation
1923	25.97	64.63
1924	17.47	74.10
1925	.59	90.43
1926 and since	.....	90.85

use of these machines, metallurgical efficiencies have been considerably improved and costs of operation have been materially reduced. There is opportunity for further progress by application of improvements in the present design and construction of these new types of flotation equipment.

It is essentially important that continued co-operation be extended to the manufacturers of organic chemicals, who are continually working with the objective of developing new reagents which alone or in combination with others may serve to assist in greater selectivity or improved recoveries.

Inasmuch as current concentration is largely a matter of proper mechanical and chemical control, it is essential that the many variables be kept within narrow limits, if possible. If this is not possible, as in the instance of the copper content of present Copper Queen concentrator heads from Sacramento Pit operations, then it is vitally necessary that concentrating operations be controlled as efficiently as possible in the light of the extreme variations in copper content of the several concentrator products. To accomplish this at Bisbee, a quick colorimetric method has been adopted, by means of which changes in copper content in concentrator products may be detected within 30 min. (See page 683.) In this way the proper control is exercised in regard to the initial tonnage which may with advantage be treated under these conditions, flotation reagents, grinding, ratios, amounts of flotation equipment advisable to use, and in the matter of concentrator losses.

Table VI—Reagents in Pounds Per Ton Flotation Solids

	1922	1923	1924	1925	1926	1927	1928, 6 Months
Chemicals	....	0.02	0.11	0.11	0.07	0.09	0.07
Oils	1.56	0.87	0.49	0.10	0.11	0.10	0.10
Totals	1.56	0.89	0.60	0.21	0.18	0.19	0.17

Table VII—Power Consumption and Distribution—Phelps Dodge Concentrators

	Kilowatt-Hours per Dry Ton				Percentage of Total Power Used by		
	Total	Crushing and Grinding	Flotation	Misc.	Crushing and Grinding	Flotation	Misc.
1924	15.21	9.76	3.35	2.10	64.17	22.02	13.81
1925	14.75	9.74	2.87	2.14	66.03	19.46	14.51
1926	14.14	9.78	2.00	2.36	69.17	14.14	16.69
1927	14.49	10.94	0.91	2.64	75.50	6.28	18.22
1928 (5 mo.)	14.45	10.89	0.91	2.65	75.36	6.30	18.34

Table VIII—Tonnage and Labor Data—Phelps Dodge Concentrators

	Dry Tons per Man-Shift			Average Number of Men per Day Shift					
	Operating	Repairs	Total	Crushing	Operators	Repairs	Tails	Misc.	Total
1925	29.52	80.70	21.33	21.8	65.8	43.8	12.2	14.2	157.8
1926	31.61	84.85	22.64	21.2	60.9	41.3	9.0	17.1	149.5
1927	33.06	86.32	23.22	20.2	57.9	39.0	7.9	15.7	140.7
1928 (5 mo.)	35.34	97.20	25.41	21.3	55.7	36.7	7.3	12.6	133.6

With harder ore at lower mine depths and in view of the need for finer dissemination of mineral in the gangue, it is important that, as a further means of proper control, frequent use be made of microscopic examination of concentrator products as an aid to desired selectivity and to insure minimum concentrator losses.

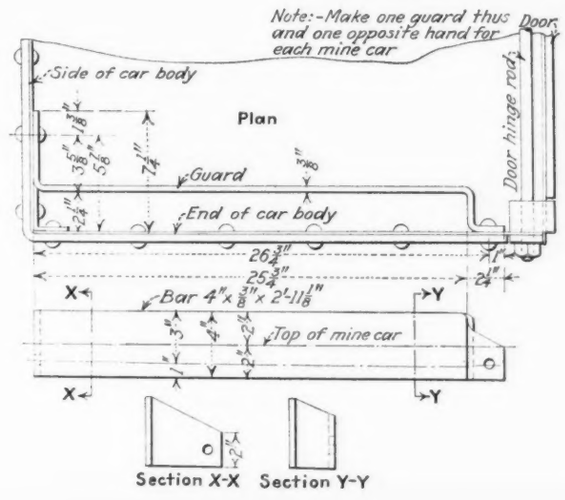
The need for proper co-operation among mine, concentrator, and smelter cannot be too strongly emphasized. The degree of selectivity sought in concentrating operations is largely dependent on smelter conditions, supplies of siliceous copper ores and miscellaneous ore receipts, and the desirability of iron and sulphur for fluxing and roasting purposes.

It is of further importance in Phelps Dodge operations, that an efficient system of interchange of information among the several concentrators be followed. In this way important developments at one branch are quickly available at the other branches. It is thus also possible to avoid duplication of test work.

Future progress in lower costs and improved metallurgy is largely associated with crushing, grinding and classification problems, especially as a present tendency is to grind finer so as to minimize losses.

Safety Hand Guard for Mine Cars

A STUDY of hand injuries in tramming at Old Dominion showed that the principal causes were (1) hand caught between car and lip of chute; (2) boulder catching on lip of chute and forced back against man's hand; (3) end of car catching hand against timbers when car is dumped, writes Charles Mendelsohn, mechanical superintendent. The guard shown in the sketch was applied to 20 cu.ft. side-dump cars, and has been effective in preventing such accidents. The end of the car body makes a more comfortable grip for a man's hands than any other part of car, and for this position the guard furnishes fairly adequate protection.



Hand guard for 20-cu.ft. side-dump mine cars

Library Facilities Are Appreciated

THE Copper Queen Branch maintains public libraries for the benefit of its employees and members of the community at both Bisbee and Douglas, according to H. C. Henrie, manager of the Labor Department. The first library was founded by the Corporation in 1887 at Bisbee. It immediately became so popular and was used so extensively that within a few years it became necessary to provide larger quarters. Later, a handsome three-story building, containing reading, correspondence, and committee rooms, was erected.

Soon after the townsite of Douglas was founded and the reduction works were removed to that point, the Corporation established a public library in Douglas. In both towns, the Copper Queen libraries are the only institutions of this nature available to the public.

About 20,000 books and 7,000 unbound pamphlets are available for circulation. The average daily number of books borrowed is 225. The reading rooms contain 110 current magazines and 30 newspapers. About 450 persons visit the libraries and reading rooms daily. The buildings are maintained and all expense of administration is borne by the Corporation.

Selective Flotation

By William T. MacDonald

Mill Superintendent, Moctezuma Copper Company

OF THE salient features of progress in the various copper concentrators of the Phelps Dodge Corporation and affiliated companies since the 1921 curtailment, the development of selective flotation has been that of chief importance. For commercial purposes, selective flotation may be defined and measured by improving ratios of concentration without damage to recoveries, where recovery is considered in terms of final profit.

At all the plants the ratio of concentration has been more than doubled since 1921. At the Morenci mill, betterment of concentrate has not been called for, in view of the requirements of the near-by smelter; improvements have therefore been in directions not concerned in the title of this paper, though of equivalent importance.

Usually, direct milling costs—including those realization costs that are largely dependent on milling efficiency—have been about cut in half by improved operation. Two revolutionary new flotation machines—the Forrester and the MacIntosh—have been originated, developed, and adopted.

At present, the Corporation has four copper concentrators in active operation, and a fifth which is idle, as shown in Table I.

The Nacozari and Copper Queen mills began operation June 1, 1922, and April 2, 1923, respectively, as new mills designed and built by H. Kenyon Burch, in collaboration with the staff of the Corporation. As built, the unit equipment and flow sheets of these two mills were almost identical, and comparison of their progress on two different ores is therefore especially significant. The Morenci and Old Dominion mills, however, are not new, though the Morenci mill has been extensively remodeled in recent years and several changes have also been made at Old Dominion.

The mineral characteristics of the feed to the four plants are essentially as shown in Table II, which has been constructed from complete chemical analyses of monthly composite samples, together with numerous concordant microscopic mineral counts made on the same samples. These determinations have frequently been made in the Corporation's central chemical and physical research laboratory, which is maintained at Douglas for such work.

Upon heads generally typified by Table II, the work of each of the four concentrators for the past several years has been as shown in Table III, which shows clearly that the trend has been toward economically maintained higher ratios of concentration and greater percentage rejection of now valueless waste. The Nacozari mill was the first large copper concentrator in the Southwest to develop selective flotation with the simultaneous banishment of all gravity concentration, which at that time consisted of roughing tables and finishing tables. Soon afterward, Old Dominion took an even longer step, going directly from a coarse-jig table-flotation flow sheet to an all-flotation flow sheet. These were the two plants where high-grade concentrate was extremely desirable, especially so at Nacozari, because of the expensive freight haul to the Douglas smelter, and nearly as important at Old Dominion, because the concentrate was treated at a custom smelter.

On the other hand, a relatively low-grade concentrate from the Copper Queen concentrator—but high in iron and sulphur—was desirable to maintain the fluxing balance in the Copper Queen smelter against other receipts there, which include the direct-smelting ores of the Copper Queen mine. Hence no need arose at Copper Queen to carry selective flotation to theoretical limits, though the balancing point has always been such as to require sufficient selectivity at the mill to eliminate the desired amount of pyrite.

It is significant of the selective work of the various branches of the Phelps Dodge Corporation, in the production of higher-grade concentrate, that the two new flotation machines now beginning to receive favorable recognition in selective flotation throughout the world were both developed within the Corporation. They were originated independently, the one by D. L. Forrester, mill superintendent at Old Dominion, and the other by J. C. MacIntosh, then general mill foreman at Nacozari.

The steps by which high-grade concentrate and maximum financial congruity have been secured at Nacozari, Copper Queen, and Old Dominion are set fourth in Table IV. Comparison will be clarified by reference to Fig. 1, which gives the beginning and present flow sheets, with equipment and assay references, for Copper Queen and Nacozari, and to Fig. 2, which gives a copper-iron-insoluble balance for Nacozari under selective practice. The fineness of grinding of flotation feed for each of the plants throughout the entire period is shown in Table V.

In essential principle, Copper Queen and Nacozari have passed through almost the same steps to attain selective flotation of all mill heads—Copper Queen working on chalcocite-pyrite and Nacozari working on chalcopyrite-pyrite. However, there have been three practical differences:

1. Finer grinding was found to be required at Copper Queen. This is mainly a function of the two different ores, Copper Queen sulphides being much more closely inter-associated. Nacozari ore, now coming from deeper mine levels, would be benefited by somewhat finer grinding than has heretofore been justified, and that step will probably come in the relatively near future.

2. The Copper Queen uses Forrester cells, whereas Nacozari uses MacIntosh cells. Each of the two installations is,

Table I—Mills, Location and Product

Branch Name Phelps Dodge Corporation	Location	Chief Copper Mineral	Average Dry Tons Milled per 24 Hours' Operation, 1927
Morenci Branch	Morenci, Ariz.	Chalcocite	4,177
Copper Queen Branch	Warren, Ariz.	Chalcocite	3,960
Burro Mountain Branch	Tyrone, N. M.	Chalcocite	Idle
Old Dominion Company	Globe, Ariz.	Chalcopyrite	1,328
Moctezuma Copper Company	Nacozari, Sonora, Mexico	Chalcopyrite	2,785

Table II—Typical Mineralogical Composition of Mill Heads

All figures in per cent

	Copper Queen		Morenci		Old Dominion		Nacozari	
	Weight	Assay Total Cu	Weight	Assay Total Cu	Weight	Assay Total Cu	Weight	Assay Total Cu
Chalcocite	2.32	1.85	2.29	1.83	0.18	0.14	0.06	0.05
Chalcopyrite	0.07	0.02	Trace	Trace	5.75	1.99	7.05	2.44
Covellite	0.13	0.09	0.07	0.05	0.05	0.03	Trace	Trace
Bornite	0.06	0.04	Trace	Trace	1.12	0.72	0.05	0.03
Native copper	.....	....	Trace	Trace	Trace	Trace	.....	.....
Tenorite	0.06	0.05	.....	....	0.01	0.01	Unspecified	
Cuprite	0.02	0.02	Trace	Trace	0.07	0.06	Unspecified	
Unspecified oxide Cu minerals	0.08	0.04	0.47	0.24	0.08	0.04	0.12	0.06
Total Cu minerals	2.74	2.11	2.83	2.12	7.26	2.98	7.28	2.58
Pyrite	17.84	....	3.90	....	12.23	....	10.34	....
Gangue, including iron oxide	79.42	....	93.27	....	80.51	....	82.38	....
Total waste minerals	97.26	....	97.17	....	92.74	....	92.72	....
Totals	100.00	....	100.00	....	100.00	....	100.00	....

of its kind, an outstanding example of the compactness and efficiency to be attained by its type.

3. Separate additional steps of concentrate cleaning were naturally evolved at Nacozari because they could be introduced—without new construction—into a plant already designed and built for but one stage of cleaning. Naturally, this method was retained in converting to MacIntosh machines, because it had consistently given a selectivity between chalcopyrite and pyrite approaching the maximum theoretically possible. Production of all final concentrate from the feed-end portion of the rougher cells at Copper Queen, with return of flotation middlings to the same point, was adopted because upon that specific chalcocite-pyrite ore a flow sheet of separate cleaning did not give equal results. The cleaning method now used at Copper Queen is to be tried at Nacozari, and good results are expected. At Old Dominion, both methods of "concentrate cleaning" are used, with satisfactory results. At Old Dominion, where the ore is essentially the same as that at Nacozari, stages of metallurgical development were not sufficiently dissimilar to warrant separate discussion here, beyond the chronology already given.

The procedure of concentrate cleaning in selective flotation may be summarized in terms of Phelps Dodge experience as follows: The selection by flotation of one mineral in particular from several is a function of time and of opportunity. Individual minerals are recovered in the progressive order of their amenability to the flotation treatment given. With an intentionally crowded condition in the cells from which the final concentrate is taken, only those particles overflow as concentrate that are most readily floatable. The others, though possibly returning several times as part of the circulating load, are unable there to overflow as concentrate because of the continued fresh influx of the preferred mineral with the feed, and are ultimately rejected with the mill tailing when the circulating load has built up to equilibrium and is no longer able to sustain them. After a sufficient period of precipitant conditioning with lime, chalcopyrite remains considerably more floatable than pyrite, inasmuch as the copper minerals can later form insoluble floating compounds with xanthate, whereas those of iron apparently are unable to do so in the presence of lime. Hence, separation on this principle is not extremely difficult. The margin of behavior divergence between *chalcocite* and pyrite under these conditions appears to be less, and hence, unless metallurgical environment is carefully controlled, repeated cleaning may result in the pyrite rather than the chalcocite being sustained. This actually began to occur at Copper Queen and caused the abandonment there of separate stages of cleaning, and the adoption of the cleaning flow sheet already outlined. As for the relation between grade of tailing and concentrate, this is to be remembered: Only two final products are made—a concentrate and a tailing; and every single particle in the feed must go to the one or to the other, so long as no further intermediate grinding is practiced. In handling mixed grains not freed by grinding, if selectivity is stringent, the particle behavior is determined by that portion that is not persistently floatable mineral, and the particle is rejected; concentrate is improved in grade by its ultimate absence therefrom, but tailing grade is increased. If selectivity is not so stringent, the reverse occurs and tailing grade is improved, but the concentrate is diluted. This condition is independent of the type of flotation machine used, the machine serving only to guard the degree of "stringency." A mixed grain either floats or it does not, and there is no middle course except intermediate grinding.

Experience at Copper Queen and Nacozari will give rise to three questions—among others—in the mind of the reader: (1) To what extent was selective flotation brought about by the use of "chemical" collectors, such as xanthate, to replace the oils; (2) was selective flotation brought about by the development of the Forrester or MacIntosh cells to replace the Callows; and (3) did finer grinding introduce any new principles?

Table IV—Chronology of Development of Selective Flotation

Nacozari	Copper Queen	Old Dominion
Lime circuit adopted, 1922.	Mill started, 1923. Lime circuit adopted in first week of operation.	All of 1922 and ten months of 1923, jigs, tables, followed by flotation. No lime.
Finishing tables shut down, 1923.	Finishing tables shut down, 1924.	Lime circuit adopted, 1923.
Double cleaning of concentrate adopted, 1923.	Roughing tables eliminated, 1924, producing all-flotation treatment.	Jigs and tables shut down, 1923.
Roughing table concentrate experimentally reground and selectively floated, 1923.	Xanthate adopted, 1925.	"T-T" flotation reagent adopted, 1923.
Roughing tables shut down and all-flotation treatment established, 1923.	Fine grinding adopted, 1926.	Xanthate adopted, 1925.
Triple cleaning of concentrate adopted, 1924.	Forrester cells adopted, 1927.	Forrester cells adopted, 1927.
Adoption of potassium (now sodium) xanthate, 1925.	Flow sheet revised to return all middlings to, and take all final concentrate from, primary cells, 1927.	
Replacement of Callow by MacIntosh cells, 1926.		

In reply it may be said that neither chemical reagents nor the new flotation machines bore any *causative* relationship to the development of selective flotation in any of the Phelps Dodge concentrators. The reagents were extrinsic, whereas the machines were definitely resultant. Finer grinding was preparatory, but probably not ingenerate, unless it should be proved that the colloidizing effects in bubble walls and at the pulp-froth boundary played a more important part than is now credited, particularly in the Copper Queen mode of circulation.

It is true that the MacIntosh and the Forrester machines have both greatly

Table III—Ratio of Concentration and Rejection of Waste

Year	Moctezuma Copper Co. Mill Ratio of Concentration	Moctezuma Copper Co. Per Cent Rejection All Waste Including Pyrite	Old Dominion Company Mill Ratio of Concentration	Old Dominion Company Per Cent Rejection All Waste Including Pyrite	Copper Queen Branch Mill Ratio of Concentration	Copper Queen Branch Per Cent Rejection All Waste Including Pyrite	Morenci Branch Mill Ratio of Concentration	Morenci Branch Per Cent Rejection All Waste Including Pyrite
1922	4.01	82.11	2.46	66.40	....	.....	5.7	84.34
1923	6.26	91.75	2.69	69.94	4.79	80.80	10.8	94.18
1924	9.28	97.61	5.43	90.24	4.49	79.18	11.5	93.49
1925	9.75	97.67	4.62	86.90	5.95	84.68	11.4	93.43
1926	11.22	98.12	5.23	89.02	6.33	85.72	11.4	93.49
1927	11.16	97.90	6.52	91.94	9.21	90.82	11.8	93.80
1928 (a)	10.31	97.52	8.00	93.68	8.05	89.79	14.2	94.93

(a) First five months.

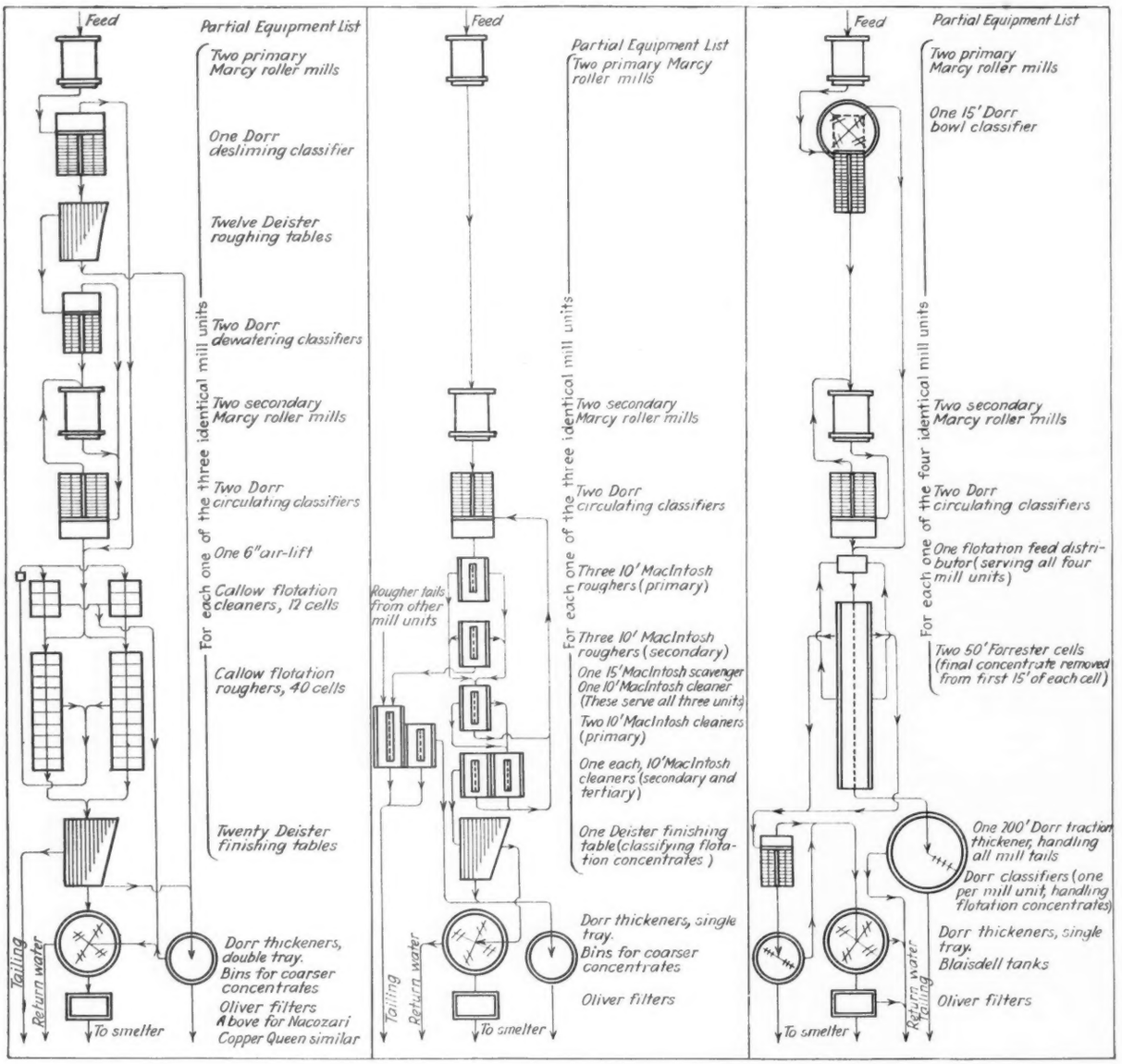
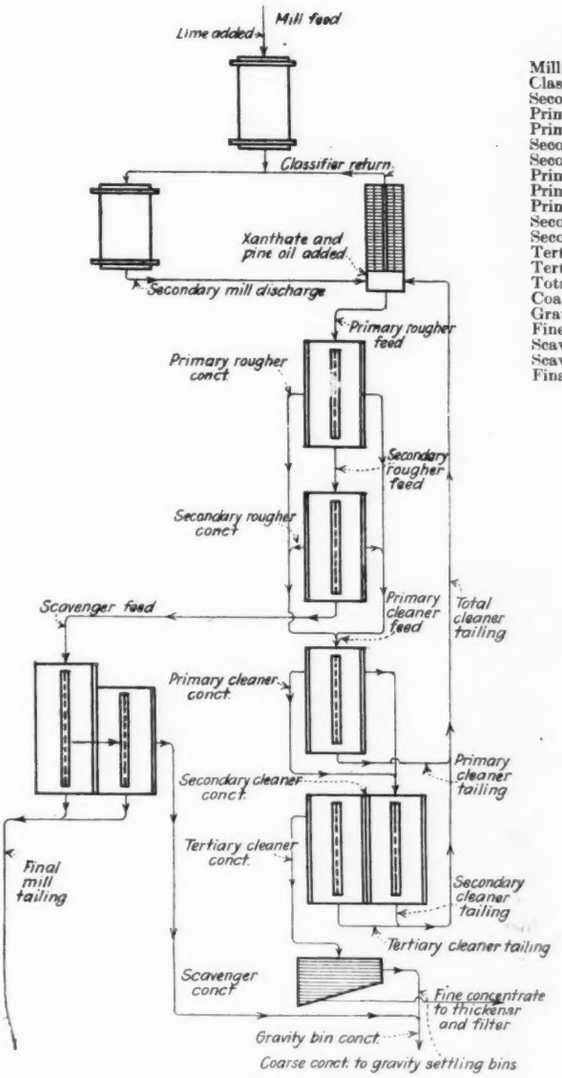

Feed
Partial Equipment List
Two primary Marcy roller mills
One Dorr desliming classifier
Twelve Deister roughing tables
Two Dorr dewatering classifiers
Two secondary Marcy roller mills
Two Dorr circulating classifiers
One 6" air-lift
Callow flotation cleaners, 12 cells
Callow flotation roughers, 40 cells
Twenty Deister finishing tables
For each one of the three identical mill units
Dorr thickeners, double tray.
Bins for coarser concentrates
Oliver filters
Above for Nacozari
Copper Queen similar
Tailing
Return water
To smelter
Feed
Partial Equipment List
Two primary Marcy roller mills
Two secondary Marcy roller mills
Two Dorr circulating classifiers
Three 10' MacIntosh roughers (primary)
Rougher tails from other mill units
Three 10' MacIntosh roughers (secondary)
One 15' MacIntosh scavenger
One 10' MacIntosh cleaner
(These serve all three units)
Two 10' MacIntosh cleaners (primary)
One each, 10' MacIntosh cleaners (secondary and tertiary)
One Deister finishing table (classifying flotation concentrates)
For each one of the three identical mill units
Dorr thickeners, single tray.
Bins for coarser concentrates
Oliver filters
Tailing
Return water
To smelter
Feed
Partial Equipment List
Two primary Marcy roller mills
One 15' Dorr bowl classifier
Two secondary Marcy roller mills
Two Dorr circulating classifiers
One flotation feed distributor (serving all four mill units)
For each one of the four identical mill units
Two 50' Forrester cells (final concentrate removed from first 15' of each cell)
One 200' Dorr traction thickener, handling all mill tails
Dorr classifiers (one per mill unit, handling flotation concentrates)
Dorr thickeners, single tray.
Blaisdell tanks
Oliver filters
Return water
Tailing
To smelter

Fig. 1—Original mill flow sheet on the left, compared with present Nacozari flow sheet in the middle, and present Copper Queen flow sheet on the right

	Metallurgical Results									
	Original Nacozari				Original Copper Queen				Present Nacozari	Present Copper Queen
	Roughing Tables	Flotation	Finishing Tables	Total Mill	Roughing Tables	Flotation	Finishing Tables	Total Mill	Total Mill	Total Mill
Feed, per cent copper	3.13	1.88	0.27	3.17	1.59	1.05	0.22	1.59	2.55	2.08
Tailing, per cent copper	1.81	0.27	0.22	0.22	1.05	0.22	0.19	0.19	0.170	0.217
Concentrate, per cent copper	10.14	17.05	2.86	11.96	5.00	8.39	4.25	6.27	27.52	15.16
Ratio of concentration, x:1	6.31	10.42	52.80	3.98	7.19	9.84	135.33	4.34	11.49	8.02
Per cent recovery, general mill heads	50.01	43.44	1.27	94.72	43.15	46.14	1.51	90.80	93.91	90.86
Concentrate, per cent iron	36.47	25.14	25.54	32.47	30.9	31.5	37.6	31.4	28.4	34.2
Concentrate, per cent "insoluble"	12.6	27.7	38.5	18.3	27.3	21.2	19.6	24.2	8.5	6.8

eased operation and have played their part in the substantial economies that have been brought about in flotation; and that xanthate in its sphere permitted similar advancement to be made. Nevertheless, the change from oils to chemical collecting reagents did not fundamentally bring about selective flotation and coincident rejection of pyrite. Nor did the introduction of new flotation machines do so; on the contrary, it was the continuing development of selective flotation that demanded a machine that would solve the resultant mechanical problem of pyrite disposal as underflow. Both the MacIntosh and Forrester machines are peculiarly adapted to the solution of this problem.

Furthermore, selective flotation was attained both at Nacozari and Old Dominion, with the older oil collectors and in the old Callow machines, before the new types of machine were in use and before xanthate had been generally accepted as a commercial success. At Copper Queen, selective flotation was similarly attained in the old equipment on oils, to the degree permitted by the liberation of the individual sulphide minerals under the conditions of grinding then being practiced; selective flotation in its present degree of effectiveness was not found to be practicable there, even with the new machines and with xanthate, until finer grinding cleared the way; then the methods already in use allowed selectivity. Paradoxically, large power savings have attended selective flotation and the plant changes in-



	Dry Tons per 24 Hours	Per Cent Total Copper	Per Cent Total Iron	Per Cent "Insoluble"
Mill feed	2,854	2.55	10.46	69.35
Classifier return	1,252.9	3.38	16.76	49.8
Secondary mill discharge	4,106.9	2.80	12.38	63.40
Primary rougher feed	3,173.4	2.49	10.44	68.57
Primary rougher concentrate	491.8	14.21	17.43	36.97
Secondary rougher feed	2,681.6	0.34	9.15	74.37
Secondary rougher concentrate	75.30	5.94	23.00	48.20
Primary cleaner feed	567.1	13.11	18.17	38.46
Primary cleaner concentrate	335.1	21.45	24.51	20.42
Primary cleaner tailing	232	1.07	9.01	64.52
Secondary cleaner concentrate	264.8	26.32	27.51	10.50
Secondary cleaner tailing	70.03	3.10	13.22	57.80
Tertiary cleaner concentrate	247.7	27.52	28.36	8.54
Tertiary cleaner tailing	17.1	8.95	15.15	38.89
Total cleaner tailing	319.4	1.94	10.26	61.66
Coarse concentrate to gravity settling bins	133	25.79	28.52	11.66
Gravity bin concentrate	136.1	25.34	28.40	11.93
Fine concentrate to thickener and filter	114.7	29.55	28.17	5.26
Scavenger feed	2,606.3	0.177	8.75	75.13
Scavenger concentrate	3.1	7.10	23.30	34.70
Final mill tailing	2,603.2	0.169	8.74	75.18

Fig. 2—Typical Nacozari flow sheet during 1927, with metallurgical results

cident thereto, as regards the flotation sections themselves, though grinding power tends to increase.

All the concentrators have used lime as a depressant for pyrite throughout essentially the entire period covered by this paper. The optimum amount was soon established and has since remained almost unchanged, this being largely a function of the natural acidity of the ore.

Other alkalizers, depressors, precipitants, and inhibiting agents, such as sodium carbonate or cyanide, have on trial been unable to displace lime, all having proved more expensive or less satisfactory for local purposes. Steam-distilled pine oil was, and continues to be, the chief frothing agent, though others have been given mill trial. As for collecting agents, these were coal-tar and creosote at the beginning of the period in all the plants. The coal-tar and creosote have been variously replaced at different times by reconstructed oils, sulphonated or sulphidized oils, "T-T Mixture," "QED" reagent, potassium or sodium xanthate, and Aërofloat, sodium xanthate now being used in all the plants.

The foregoing does not imply that the oils possess all of the flotative properties of xanthate. The term "adsorption," as commonly used to interpret certain flotation phenomena, may be somewhat of an ambiguity, but with xanthate, the evident precipitation of the insoluble, yellow, readily floating copper-xanthate compound is unmistakable. Lime assumes the important function of protecting xanthate by impeding its precipitation by soluble iron, though happily permitting the corresponding reaction with soluble copper. Sodium sulphide, or even an excess of sodium xanthate itself, might well serve some functions of lime, except as the wastage of these more expensive reagents by soluble iron might be intolerable. The discriminating precipitation of the latter is desirable. In a lime circuit, the relatively low solubility of calcium xanthate may be a disadvantage.

During the trial of various flow-sheet modifications seeking increased selectivity, the making of a pyritic table concentrate or of a bulk flotation concentrate followed by a separate regrinding and selective flotation of this reground product was tried at both Copper Queen and Nacozari. The mill tests of this nature at Nacozari during July, 1923 ("Selective Flotation at Nacozari," *E. & M. J.-P.*, Vol. 118, No. 12, p. 450) are noteworthy, in that they yielded results metallurgically as satisfactory as any that since have been attained. For economic reasons, this scheme was not definitely adopted there, though it has always been considered not only sound in principle but also to possess certain unique advantages where the character of the local ore warrants its use. After due trial, Copper Queen decided in favor of present methods of bulk fine grinding, as has Morenci also. Old Dominion, however, has recently taken renewed interest in separate regrinding of pyritic concentrate. Laboratory tests have shown Tyrone ores also to be readily amenable to separate-concentrate grinding, yielding a high-grade final concentrate and high selectivity between chalcocite and pyrite.

Close control has been recognized as an essential to the maintenance of best average results in all the plants. Tonnage-feed rate, pulp densities, alkalinities, reagent quantities—and, sometimes, colorimetric coppers—are determined within the mill at suitable intervals, in addition, of course, to automatic sampling at key points and accurate determination of the significant constituents. At Nacozari, as a control upon alkalinities and *pH* values, a continuous, recording, electrical conductivity meter has been in use for the last four years; this is a self-balancing Wheatstone bridge giving a continuous graph of dissolved-lime variations. At Nacozari also, where new porous media for flotation machines are being developed, the porosity of materials under investiga-

Table V—Screen Analyses—Per Cent Cumulative Weight in Flotation Feed

	Copper Queen			Old Dominion			Nacozari		
	Minus 48 Mesh	Minus 100 Mesh	Minus 200 Mesh	Minus 48 Mesh	Minus 100 Mesh	Minus 200 Mesh	Minus 48 Mesh	Minus 100 Mesh	Minus 200 Mesh
1922	No operation			98.35	73.42	54.55	97.49	74.73	57.10
1923	75.69	79.39	56.88	99.70	78.22	59.38	92.47	68.32	50.55
1924	96.51	77.36	52.76	96.88	76.77	55.52	89.14	65.73	51.36
1925	98.50	78.46	54.70	95.67	75.13	53.40	86.57	63.59	48.75
1926	98.65	79.98	55.05	96.90	75.70	54.50	88.39	63.97	50.59
1927	99.89	92.18	69.71	97.32	77.50	56.23	87.25	65.66	52.96
1928 (a)	100.00	92.86	71.29	96.27	74.60	53.50	88.00	68.74	55.00

(a) First five months.

tion is determined by measurement of air passed by unit area in unit time. Flotation is, before anything else, a process of aëration; air is itself a "flotation reagent" not outranked by others in importance. The manner and quantity of its addition; the degree of its comminution, affecting its buoying power and its opportunity to meet the mineral it is to transport, are phenomena to be scrutinized carefully by all concerned.

Ore-dressing control and contemporaneous knowledge of the behavior of all significant mill variables are coming to be regarded as of growing importance in all the mills, and in some instances, not alone "close" control, but means for ultra-refined control, are being sought. Titration of free xanthate in flotation tailing may be mentioned.

Throughout all of the period concerned in this paper, operations of the mills have been in charge of the following superintendents: Arthur Crowfoot, at Morenci; Ernest Wittenau, at Copper Queen; D. L. Forrester, at Old Dominion; William T. MacDonald, at Nacozari; with W. B. Cramer as consulting engineer for the Concentrating Department of the entire Corporation.

Copper Queen Smelter

By P. G. Beckett

General Manager

THE COPPER QUEEN smelter was erected in 1904 and as built comprised five 18-in. blast furnaces and four barrel-type acid-lined converters. Later, this was increased to ten blast furnaces and seven converters.

In 1912, a roaster-reverberatory plant, consisting of two reverberatories 24 ft. 8 in. x 94 ft. 1½ in. and six 18-ft. diameter six-hearth McDougall roasters, was built for the treatment of concentrates and flue dust. Later, a third reverberatory was added, and successive additions brought the roaster equipment up to twenty 18-ft. diameter six-hearth McDougalls. At this time the converter equipment was changed to eight stands of basic-lined 12-ft. diameter Great Falls-type converters.

Beginning in 1917, efforts at this plant have centered on improvements in roaster-reverberatory practice. At the end of 1917 the form of the reverberatory furnace was changed from the drooping arch, standard up to that time, to the horizontal or straight-line arch, and the uptake area was enlarged. By this means the capacity of these furnaces was increased from 325 tons to 650 tons per furnace day. About this time the effect of loss of temperature of calcines in the transfer from roaster to reverberatory was definitely evaluated, and the possible savings by avoidance of this loss were demonstrated. Subsequent improvements in technique, particularly by increase in speed of combustion in the furnace and to some extent by conservation of calcine heat, brought the capacity of these furnaces up to 800 tons per furnace day.

A study of roasting resulted in the building of a trial unit having nine hearths and differing in design from the previous roasters. This would roast twice as much as the six hearths, and was self-sustaining thermally on a sulphur content of 2 to 3 per cent less than that required for a self-sustaining roasting in the six hearths. Experimentation with this roaster led us to believe that by superimposing more hearths, tonnages greatly in excess of this could be obtained from a roaster occupying no more floor space than the original six-hearth McDougall. Metallurgists had long wanted to put roasters over reverberatory furnaces; the development of a high-tonnage roaster occupying a small floor space made it possible to superimpose over a reverberatory furnace sufficient roaster capacity to supply the needs of a modern reverberatory furnace.

The new roaster reverberatory plant of the Copper Queen Smelter, put in operation early in 1927, embodies this feature. There are two units, each of which consists of a reverberatory furnace 96 ft. x 26 ft. 9 in., with four 520-hp. Erie City waste-heat boilers for the utilization of the heat of the furnace gases for the production of steam.

Each reverberatory has six eleven-hearth 19-ft. diameter Queen-type roasters superimposed above it. The roasters are arranged in two rows of three, transverse to the longitudinal axis of the reverberatory. The roasters discharge their product by gravity through heat-insulated pipes into one or the other of two 150-ton (rated-capacity) calcine bins, and the roasters are set high enough above the bins to permit the discharge by gravity of calcines from any one roaster to the bin under the adjacent roasters.

From the calcine bins the calcine flows by gravity through pipes to the furnace charge holes. The roaster gases pass through Cottrell treaters for the recovery of the dust. Each battery of six roasters has above it a battery of four pipe treaters, each of which has 140 eight-inch pipes. The gases enter near the top of the treaters, flow down outside the pipes, turn and ascend through the pipes, where they are subjected to the electric discharge, and pass into a balloon flue and thence to the stack. Dust from the treaters flows by gravity through pipes to the calcine bins.

The roaster uptakes, the flues to the Cottrells, the Cottrell treaters themselves, and the balloon flue leading to the stack, as well as all flues from the waste-heat boiler outlets up to the stack, are built of steel, covered with high-grade heat-insulating material to prevent acid corrosion and infiltration of air. A stack, 350 ft. high by 17 ft. 2½ in. inside diameter at the top, discharges the gases into the air.

The reverberatory plant is situated on the south side of the old converter aisle, and its product is converted there to blister copper, using 12-ft. Great Falls converters, of which there are eight stands, a maximum of six being operated at any time.

The superimposition of roasters over reverberatories was a distinct departure from standard practice; and, in the operating of the plant, some of the troubles usually incidental to pioneering have been encountered. Changes necessary to overcome these troubles are under way, but inasmuch as they must be made while the plant is in operation,

some time will elapse before they are all completed. Until that time, when the maximum possibilities of this type of roaster-reverberatory plant will be realized, the operators do not wish to publish a detailed account of its performance.

In spite of these troubles and of the fact that thereby the full benefits of a superimposed roaster-reverberatory plant are not being obtained, performance now is equal to the estimate made prior to construction. The present results may be briefly summarized by the following figures for three months—March, April, May, 1928:

Reverberatory furnaces treated 998 tons, solid charge, per furnace day, with a gross fuel ratio of 0.405 bbl. oil per ton of solid charge (equivalent to 2,562,000 B.t.u. per ton of solid charge). Waste-heat steam production amounted to 7.35 lb. steam from and at 212 deg. F. per pound of oil burnt in the reverbs.

Roasters averaged 237 tons per day, solid charge, per furnace day, from 23.7 per cent sulphur to 12.9 per cent sulphur. The sulphur removal per square foot of hearth area per day was 28.9 lb. Fuel consumption was 0.001 bbl. of oil per ton of charge. A test run of one roaster showed that it could roast per day 335 tons of charge (dry weight) containing 5.5 per cent moisture and 21.8 per cent sulphur, down to 10.4 per cent sulphur, without fuel. The sulphur removal in this case was 39 lb. per day per square foot of hearth area.

The combined direct gross cost of roasting, reverberatory smelting, and dust recovery (total smelting cost, exclusive of ore preparation, converting, and slag disposal), was about $1.27 per ton; fuel credit amounted to 41c. per ton, leaving a net direct cost for these operations of 86c. per ton.

Colorimetric Copper Method Proves Valuable Control Tool

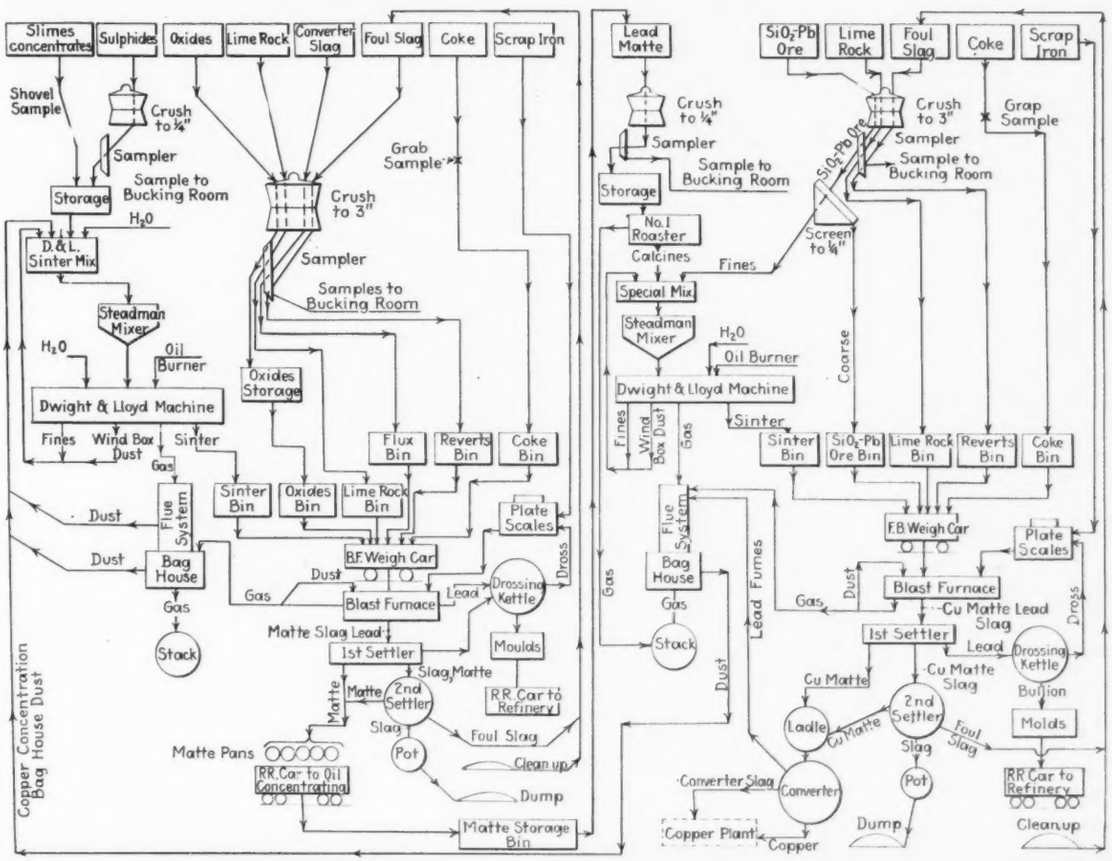
A FEATURE of operation at the Copper Queen concentrator for the last year and a half has been the use of the colorimetric method for making immediate copper determinations on various mill products, states E. Wittenau, concentrator superintendent. This work was started at a time when considerable experimentation was being done in the flotation department, and the quick results obtained were found greatly to facilitate progress. Subsequent operation has proved the calorimetric method to be highly advantageous in keeping a close check on mill operation and detecting abnormal conditions as soon as they arise.

The method employed is simple. Samples of feed, concentrate, and tailing are taken, dewatered in a pressure filter, and dried on a hot plate. The sample is then cut down, weighed, and given a standard nitric-acid digestion. Ammonium hydroxide is added later to precipitate iron and to form the familiar blue copper hydroxide. This solution is then compared with a solution derived in the same manner from a standard pulp of known copper content, the comparison being made in a colorimeter, which consists of two graduated glass cylinders mounted over a reflected light, together with an eyepiece equipped with two separate mirrors superimposed above the cylinders. One cylinder contains the standard solution; the unknown sample is placed in the other. The level of solution in the standard cylinder is regulated by an outside tube and plunger. By manipulating this plunger, the level of the standard solution is raised or lowered, which changes the color density to permit direct comparison with the color of the unknown solution.

When the two colors, reflected in the morrors of the eyepiece, are matched, a reading is taken on the standard graduated cylinder. For example, if equal weights of sample and standard are taken, and the standard assays 0.50 per cent copper, when the colors match with the standard tube exactly half full, then the unknown must assay 0.25 per cent copper.

The apparatus requires little space and is conveniently located in the flotation department of the mill. Samples are taken hourly, and determinations are known within thirty minutes. Assays so obtained check standard potassium iodide assays within 5 per cent of the copper content.

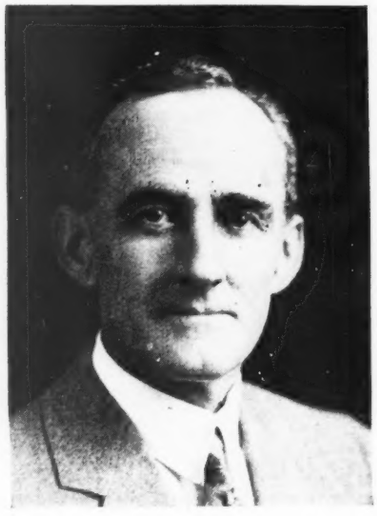
Flow sheet of lead plant, Copper Queen Branch



Electrical and Mechanical Testing

By H. H. Pratt

Chief Engineer, Mechanical Engineering Department



ON ACCOUNT of the rush of new construction and high pressure operations during the World War, little attention was given to efficiency of equipment; also, owing to the difficulty of obtaining delivery on new machinery, equipment was installed which was not highly efficient, and repairs and maintenance on all equipment were neglected. Then came the collapse of the copper industry and virtual shutdown of all operations in 1921. Upon a resumption of operations under conditions of high labor and material costs and low-priced copper it was evident that efficiency in every department was necessary in order to lower production costs.

For some years before the war the consulting mechanical engineering department had a test engineer, whose duties consisted of going around to the various branches and conducting tests on power and mechanical equipment. As it was difficult for one man adequately to cover the ground and give the necessary time to each branch for this work, it was decided that each branch should have a test engineer and maintain a systematic routine of tests on all principal power and mechanical units, and also make special tests on equipment that was apparently inefficient or not suited to the work. The consulting mechanical engineering department therefore drafted the following general instructions and a test schedule for each branch similar to that given below for the Morenci Branch.

General Instructions for Conducting Tests on Mechanical and Electrical Power Equipment

Water Meters—Whether meter is of the periodic-dump type or continuous flow, such as the V-notch, it should be calibrated by checking the actual weight of water discharged, where possible, and not by tank measurements, which are often deceptive unless the tank is sufficiently small and carefully calibrated. Several measurements should be made and final results taken as the average of these readings.

Boilers and Economizers—An eight-hour test should be made during the day shift when the heaviest load is being carried, to determine if boiler condition and firing are correct for maximum efficiency. Also, a 24-hour test should be made to determine if daily and monthly figures are correct.

All readings on boiler tests should be taken at fifteen-minute intervals, and a complete cut-off made at the end of every hour by taking oil, water, and gage-glass readings so that if boiler "pops" or anything happens to spoil the test, any one hour can be eliminated and the remainder of the test will still be accurate.

Superheaters—At the Copper Queen Branch, at Douglas, is the only plant that has separately fired superheaters on which a test can be made. This test would consist of measurements of oil used and steam superheated, with readings on the quality of steam into and out of superheater.

Steam Compressors—Compressors should be indicated and valves and pressures adjusted to the best possible condition, and a steam-consumption test run where plant arrangement allows. Readings to be taken every fifteen minutes and hourly cut-off on steam and air made. At plants where the arrangement of steam and air piping is such that steam consumption tests cannot be made, indicator cards on both air and steam should be taken, and adjustments made to give best possible efficiency.

Furnace Blowers and Converter Blowing Engines—Arrangements at Douglas and Clifton are such that it would be difficult to obtain steam consumption and air output on individual engines, but at both places tests can and should be made on the air plant as a whole, steam consumption to be obtained from meters, and air output from pitot tube or meter readings. All engines should be indicated, and necessary adjustments made for best efficiency.

Electric Engines—No steam consumption tests can be made on these, but indicator cards should be taken and necessary adjustments made for maximum efficiency.

Steam Turbines — Steam-consumption tests should be made either by meter measurements of steam, or, in case of surface-condenser equipment, by measuring condensate discharge. An eight-hour test should be made at the time of heavy load; also a 24-hour test to check the results of daily and monthly figures.

Condenser Systems — Condenser-system tests can probably be most conveniently made at most of the plants in conjunction with either turbine or compressor tests, which give the amount of steam to condensers, and the eight-hour test would be sufficient.

At some of the plants the quantity of cooling water circulated cannot be accurately measured, and pump displacement will have to be used to estimate this figure, but the readings such as of vacuum and temperatures will show if this figure is fairly correct and whether pumps are in efficient condition. When actual weir measurements of water can be made, this should be done.

Steam Hoists—Hoists should be indicated and adjusted for maximum efficiency, and then a steam-consumption test made covering a hoisting shift. On skip hoists all data regarding work done by the hoist should be recorded. On dinkey hoists the number of revolutions is about all that can be accurately accounted for. Steam measurements should be obtained from the evaporation of boilers used on hoists only.

Steam Pumps—Pumps should be indicated and adjusted for maximum efficiency, then an eight-hour test made for steam consumption and water pumped. Steam measurements should be obtained from evaporation of boilers used on pumps only, and water measurements by meter or weir measurements.

Electric Pumps—All large electric-pumping units should be tested by obtaining power-input and water-discharge measurements to determine the condition of the pumps. A three- or four-hour test should be sufficient. At some of the plants it will probably be necessary to obtain water-discharge measurements. On units taking a fairly large amount of power this should be done.

Diesel Air Compressors—The engines should be indicated and adjusted; the air compressor should be indicated and adjusted, then either an orifice or a meter test made on the air output, with fuel consumption readings on the engine at the same time, to determine fuel consumption per million cubic feet of air compressed.

Electric Compressors—The compressor should be indicated and adjusted, then either an orifice or a meter test made on the air output, with electric-meter readings at the same time to determine kilowatt-hours per million cubic feet of air compressed.

Ventilating Fans—Measurements should be made on the water-gage pressure and the volume of air delivered, with readings on electric power input to the motor taken at the same time.

Electric Meters — Watt-hour meters should be checked with a rotary standard, and adjusted if showing more than 1 per cent error. Indicating meters should be checked if they are apparently reading incorrectly, and if badly so, they should be returned to the manufacturer for repairs and adjustment.

Steam and Air Meters—Steam and air-flow meters should be checked in accordance with instructions from the makers. If they cannot be adjusted locally they should be returned to maker for repairs and adjustment.

Gages—All steam and air-pressure gages should be tested at least once a year. At any time that gages are apparently reading wrong, they should be tested and adjusted at once.

Morenci Branch—Test Schedule

Item Number	Equipment to Be Tested	Time Schedule
1	Boiler plant water-meter	Monthly
2	Boiler plant efficiency	Every 4 months
3	Steam compressor	Every 6 months
4	Blowing engines	Every 6 months
5	Turbines	Every 4 months
6	Turbine condenser system	Every 4 months
7	Diesel compressors	Every 4 months
8	Electric compressors	Every 6 months
9	Electric hoists	Every 6 months
10	Ventilating fans	Every 6 months
11	Electric meters—generator and main feeder	Monthly
12	Steam and air meters	Every 4 months

As will be noted in the general instructions, the varied equipment and arrangements require different test procedure at the various plants. The results of these tests are submitted to the Consulting Mechanical Engineering Department for comment in regard to the condition of equipment or recommendations for improving efficiency.

During the past eight years a large proportion of our electric power at the various branches has been generated with Diesel-engine generating units, and we have found from experience that to get maximum efficiency and operating time, various details of maintenance must be attended to frequently. On these units we have therefore adopted a different system from the periodic tests as outlined above.

All the Diesel plants are equipped with individual fuel-measuring tanks for each engine, carefully calibrated so that the daily, or even hourly, fuel consumption can be noted, and the kilowatt output and fuel consumption for each eight-hour shift recorded in the daily log. Aside from the visible signs of trouble, one of the surest signs that an engine needs attention is an increase in fuel consumption, and this can readily be checked by the operating engineers by the readings on the fuel-measuring tanks and generator watt-hour meters. Some of the engines are also equipped with pyrometers, so that readings can be taken on the temperature of the exhaust gases of each cylinder, which gives a quick method of locating the cylinder or cylinders on which there is trouble and cause for high fuel consumption. No adjustments or changes are made, however, until indicator cards are taken on these cylinders and the actual cause of the trouble is determined. We therefore consider that our Diesel units are practically under test daily and that general tests at stated intervals are not required.

The necessary tests to determine the efficiency of electric-power generating equipment are important, but of almost equal importance are the tests and maintenance of efficiency on air-compressor equipment. As a large proportion of our air units are primary power units—either steam or Diesel-engine driven—the test work is more difficult than with electric motor-driven units.

A large part of our power-plant equipment must be in operation at least sixteen hours, and some of it 24 hours, per day, so the difficulties encountered by the test engineer can be imagined, and progress in making necessary adjustments and repairs which are indicated by the tests is often slow.

Probably one of the greatest benefits obtained from having a test engineer on the job is the moral effect on the plant operating force; for the power-plant engineer is much like the rest of us—inclined to put off doing the little odd jobs, such as adjusting a valve or replacing worn packing, until some convenient time when the engine is down for a general overhauling; but with the prospect of a test being run on that engine, he will use every opportunity to put it in the best possible condition beforehand, and the net result is better general condition of equipment, even without the improvement that can be made as a direct result of tests. As mentioned above, our operating conditions are such that it is often difficult to shut down equipment for the necessary repairs and adjustments to maintain maximum efficiency, but the direct and indirect results of our power-plant tests show substantial savings in power-generation costs.

In copper production, perhaps more than any other industry, the changes in methods and equipment during the last eight years have been rapid and somewhat radical, and, because of the narrow margin of profit, investment in new equipment, unless absolutely necessary, has been kept at the minimum. The result of this has been the gradual accumulation of a great deal of mechanical and electrical equipment not exactly suited to the work, and which therefore operates inefficiently.

Complete operating and cost data are kept on the power-plant operations, and these figures are carefully watched each month by the branch and Corporation officials, and a slight decrease in efficiency and increase in power costs requires an explanation. On the other hand, it is, of course, difficult to keep any complete records on the ultimate use of this power. The result is that a large part of the savings to be credited to efficient and economical generation of power are lost on account of inefficient distribution and application. As no records showing these losses in dollars and cents are kept and brought to the attention of the officials, they have urged the use of equipment on hand, for the sake of economy, regardless of whether or not this equipment is suitable for efficient operation.

In view of these conditions, we decided some time ago that an important part of the power-efficiency job was to determine exactly how the power was distributed and used. With this object in view we have been making complete power surveys at the various branches, two of which have been almost completed. These power surveys start with the generator and feeder meters at the generating stations and check transmission and transformer losses to the motor distribution panels. Then, by means of graphic meters, a power-input test is made on each motor to determine starting load, running load, and power factor. From this power-survey information many details that affect our power losses can be readily determined, the most important of which are as follows: Correct size of transmission lines for load carried, correct size and voltage at transformer banks, correct size of feeder distribution to motors, correct size of motors for load conditions, and actual power required to drive equipment, this last item being determined from the actual power input reading, using the manufacturer's guarantee for motor efficiency. These figures also give a direct comparison of the efficiency of two machines doing the same work.

Two of the largest factors in electric-power losses are over-motoring and the use of slow-speed low-efficiency motors. In many plants the required starting torque will be the determining factor in selection of size and type of motor, and this often results in an installation where the running load on the motor is less than one-half full load, with resultant low efficiency and power factor.

For many years the power-factor conditions on alternating-current systems were given little consideration, but in recent years—with the tendency to load generating equipment to the limit in order to obtain minimum power costs—high power factor is important, as the maximum kilowatt load that can be carried on the generator will vary directly as the power factor of the load. Power factor also affects transmission and transformer losses to some extent.

To raise the load-power factor, synchronous motors are being used extensively, especially on applications that require slow-speed motors. In combination with a magnetic clutch they make a satisfactory drive for slow-speed applications requiring high starting torque. This combination makes available the full pull-out torque of the motor for starting the load.

We are gradually making changes in equipment based on the information obtained from these power surveys and will eventually show some substantial savings effected by the avoidance of unnecessary power losses.

Diesel Power

By C. Legrand

Consulting Mechanical Engineer

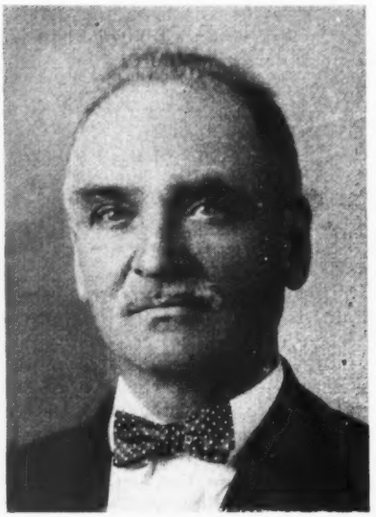
SINCE 1905 Phelps Dodge Corporation has been interested in the savings in power costs obtainable by the use of Diesel engines where fuel oil is available. The company in that year tried to import a 3-cylinder, 525-hp., 4-cycle engine, but was prevented from doing so by the patent situation. No American-built engines with cylinders of more than 75 hp. each were then available, and not until the basic patent expired were larger cylinders built in this country.

Two single-cylinder 75-hp. engines were used by Phelps Dodge at a limerock quarry near Douglas to drive air compressors. These engines ran satisfactorily for about two years before the quarry was abandoned in 1910.

In 1912, I investigated the progress made in Europe in Diesel-engine construction, and in 1913 the company ordered from Belgium two 5-cylinder, 2-cycle 180-r.p.m. engines to drive 815 kva., 60-cycle, 6,600-volt generators. These engines were installed in 1914 at the plant of the Burro Mountain Copper Company, Tyrone, N. M., at an elevation of 6,000 ft. above sea level. At sea level the engines were rated at 1,250 hp. and they were guaranteed to deliver 1,000 hp. at Tyrone. Under tests at Tyrone they delivered 1300 hp. for short periods, and over 1,200 hp. for periods of four hours. The fuel oil was ordinary California 16 deg. Bé., similar to that used in boiler plants of the company at other points. A full description of the Burro Mountain Copper Company plant is given in a paper written for the A.I.M.E. in 1916.

Doubt was freely expressed during the construction of the plant that the engines could be run satisfactorily with the generators in parallel. This was fully tested as soon as the two engines were installed, and it was found that parallel operation was superior to that of cross-compound steam engines, and that under any condition likely to appear in regular operation the generators could not be made to fall out of step. Since then plants have been run with five engines in parallel, as well as with steam turbines on the same circuit.

A short description of the test is given in a paper written in 1915 for the A.I.E.E. In the same paper are given the reason for choosing the then less-tried two-cycle engine instead of the four-cycle engine. One of the principal reasons was the greater freedom in fuel-oil choice and the ability



of the two-cycle engine to use high-sulphur oil. This was soon tested and proved to be correct, and for five years the engines were operated with Mexican fuel oil containing 3½ to 4½ per cent sulphur, with no marked increase in maintenance or lubricating costs.

The operating costs obtained at Tyrone led to the use of Diesel engines in other plants where additional power was required. Larger units were desirable, and in 1920-21 four 4-cylinder, 120-r.p.m., 1,800-hp. engines at 5,000 ft. elevation were ordered and installed in Nacozari, Mexico, and at Bisbee, Ariz. Under test these engines developed satisfactorily a much greater power than expected, and are now rated at 2,200 hp. at sea level. These engines were for several years the largest Diesels in use in this country, as the 1,250-hp. engines had been before them. To our great satisfaction the larger engines have proved easier to maintain and cheaper to operate per horsepower output than the smaller size. Part of this saving is due to the slower rotative speed and better fuel efficiency.

The greatest trouble experienced in the early days of operation was the cracking of cylinder heads. At one time this assumed a serious aspect, and I devised a replaceable inner head which reduced the maintenance cost materially and allowed experimental metal compositions to be used at small expense. By the use of special cast steel, this trouble has now been eliminated.

When Phelps Dodge Corporation started using Diesel engines, operators had to be trained and costly mistakes were often made. Most of the engines were built in this country during the war period, when it was difficult to get the materials wanted, and our present maintenance costs are still affected by these causes. Perseverance, the full co-operation of the operating forces and of the manufacturers have overcome the troubles and difficulties inherent to pioneering work. The financial results have been satisfactory, and the average cost of power, including capital charges during the whole period of operation, has been less than could have been obtained by other means of generation. The maintenance cost, instead of increasing as the plants get older, is still diminishing.

The engines have also been adapted to variable-speed air-compressor drive with a range of speed of one-half to full speed and are very satisfactory in this service, as there is no cause for overloading the engine.

Phelps Dodge Corporation is probably the largest single user of large-size Diesel engines in this country, as shown in Table II.

Representative running costs for the year 1927 based on using 16 deg. Bé. California oil at $2.10 per barrel are given herewith. They are for available kilowatt-hours, after deducting from total production the necessary power-house auxiliaries and lighting.

Table I—Cost per Available Kilowatt-Hour at Switchboard

	No. 1, Cents	No. 2, Cents
Operating labor	0.045	(a) 0.116
Engine repairs	.139	.054
Other repairs	.019	.....
Lubrication	.028	.016
Water	.014	.....
Supplies	.004	.....
Fuel oil	.493	.410
Miscellaneous	.017	.....
Total	0.759	0.596

(a) Includes other items not given below.

Cost No. 1 is at a plant with 1,250-hp. engines only. These are rated by us at 700 kw. at the elevation of the plant; the average load during the year was 101 per cent of rating, with peaks of about 125 per cent of rating. This high load was maintained because the plant runs in parallel with a steam-turbine plant, which takes most of the peaks. Repair costs include one broken shaft.

Cost No. 2 is at a plant with both 1,250-hp. and 2,200-hp. engines, but applies only to the 2,200-hp. engines,

Table II—Phelps Dodge Diesel-Engine Plants

Tyrone	2—5 cylinder 1,250 hp. 180 r.p.m.; driving generators 2—3 cylinder 750 hp. variable-speed; driving air compressors
Morenci	5—5 cylinder 1,250 hp. 180 r.p.m.; driving generators 1—5 cylinder 1,250 hp. variable-speed; driving air compressors
Globe	2—5 cylinder 1,250 hp. 180 r.p.m.; driving generators
Bisbee	2—5 cylinder 1,250 hp. 180 r.p.m.; driving generators 2—4 cylinder 2,200 hp. 120 r.p.m.; driving generators
Nacozari	4—5 cylinder 1,250 hp. 180 r.p.m.; driving generators 2—4 cylinder 2,200 hp. 120 r.p.m.; driving generators
Pilares	2—3 cylinder 750 hp. variable speed; driving air compressors

which are rated by us at 1,300 kw.; and the load is quite variable, as there is no other source of power at this plant. The average load on 2,200-hp. engines was 97 per cent, and peaks were about 125 per cent. Costs given do not include taxes, general company overhead, or capital charges.

The cost of compressed air per million cubic feet compressed to 90 lb. gage, with fuel oil at $2.10 per barrel, was $15.04 in a large compressor that is part of a complete Diesel plant and has only to stand its share of operating labor and general expense. In a self-contained compressed-air plant with two smaller air compressors, the cost was $18.02 per million cubic feet. A high-grade self-contained steam-compressor plant with triple-expansion superheated-steam engines driving a cross-compound air compressor with a total output 65 per cent greater gives us a cost of $26.19.

Prior Organization Simplifies Fire Fighting Underground

COPIES of instructions for handling underground fires are given to each Copper Queen employee concerned. In addition, cards are posted at the shaft stations, timber station, and various other places underground, telling the men underground what to do if a fire occurs, states F. H. Hayes, mine superintendent, Copper Queen Branch.

Large signs are placed on valves controlling the stench in the air line, for turning water into the air lines, for closing fire doors, and showing the ways to the mine exits. Instructions for handling underground fires are as follows:

In case of a fire starting in the mines, the first consideration must be the safety of the men; when all have been accounted for, attention shall be given to the saving of property. There must be no changes in ventilation except on the written orders of the mine superintendent or general foreman.

Duties of Man Discovering Fire—(1) Notify nearest men of location of fire; (2) send first man notified to shaft to notify engineer and cager of location of fire. Call cage by emergency signal of seven bells, followed by station signal —all on annunciator. This man goes to time office and waits until checked off by his shift boss; (3) second man notified goes to nearest mine phone to notify hoist engineer of location of fire. This man goes to the time office and waits until checked off by his shift boss; (4) the man who discovered the fire then proceeds to the time office, warning all men on the way.

Duties of All Other Men Underground—All other men underground shall immediately proceed to the time office and wait until checked off by their respective bosses.

Duties of Shift Boss—(1) Proceed to the time office, check all his men, and notify his foreman of the results; (2) hold all men and await further orders; (3) if a man is missing, search must not be made except under direction of the mine superintendent or general foreman.

Duties of Division Foreman—(1) Proceed to his time office; (2) place guards at all mine entrances to prevent men from entering mine without written instructions from the mine superintendent or general foreman; (3) these instructions shall contain the name of each man, the level to which the party is going, the time the party goes underground, and the signature of the mine superintendent or general foreman; (4) send cagers to collars of all shafts; (5) report all men missing to the mine superintendent or general foreman; (6) organize apparatus crews to search for missing men; (7) organize fresh-air and first-aid crews; (8) await orders of the mine superintendent or the general foreman.

Duties of Mine Superintendent and General Foreman—(1) Proceed to division office at scene of fire; (2) receive reports from division foreman, chief engineer and master mechanic on missing men; (3) receive reports from division foreman on rescue crews; (4) receive report from safety inspector on safety equipment; (5) receive report from service foreman on rescue supplies; (6) receive ventilation maps from chief engineer; (7) issue written orders to division foreman regarding ventilation for search for missing men; (8) issue orders for search for missing men and sign passes; (9) report to manager of action taken; (10) consult with manager, master mechanic, chief engineer, safety inspector, mine inspector, and foreman, and formulate plans to fight the fire.

Duties of Supply Department—(1) Manager of supply department will proceed to supply department; (2) notify warehouseman and truck drivers to report for duty; (3) organize personnel for 24-hour service; (4) prepare to issue standard supplies.

Duties of Cagers, Hoist Engineers, Oilers—(1) Cagers, hoist engineers, and oilers shall not leave their posts until relieved; (2) cager or oiler will release stench in air line; (3) cager or oiler will give alarm on electric switch: —— flashes, repeated; (4) cager or oiler will notify central telephone operator by saying "Copper Queen Fire Call ——— Shaft"; (5) when any hoist is notified of a mine fire at any other shaft, the oiler will at once release stench in his air line and give fire alarm on electric switch.

Duties of Supply Boss—(1)Proceed to office at scene of fire; (2) report all men missing to general foreman; (3) assemble and send all apparatus men to division foreman; (4) organize supply and transportation crews; (5) order supplies for rescue and fire-fighting work and arrange for checking and delivery underground; (6) await orders from mine superintendent or general foreman.

Duties of Chief Engineer—(1) Proceed to engineering office; (2) check all engineers and report men missing to general foreman; (3) organize all engineers for rescue and fire-fighting work; (4) take ventilation maps to fire division and there await orders from the mine superintendent or general foreman.

Duties of Safety Department—(1) Safety inspector will proceed to safety building; (2) proceed to prepare rescue equipment for transportation by mechanical department or fire department to scene of fire; (3) organize reserve rescue crews; (4) assistant safety inspector will accompany rescue equipment to scene of fire; (5) notify medical department to keep a doctor at the scene of fire; (6) organize a first-aid station at the scene of fire; (7) safety inspector will report at the scene of fire.

Duties of Mechanical Department—(1) All employees working underground will proceed to the mechanical department time office to be checked and await further instructions; (2) master mechanic, chief electrician, pipe foreman, and surface foreman will proceed to master mechanic's office; (3) master mechanic will send engineers to all shafts; (4) master mechanic will report all men missing to the mine superintendent or general foreman at scene of fire; (5) master mechanic will organize apparatus men and send them to foreman at scene of fire; (6) organize transportation crews; (7) master mechanic will notify all other foremen of the fire; (8) master mechanic and chief electrician will then report at the scene of the fire.

Safety Methods

By Everard Leland

General Superintendent, Moctezuma Copper Company

EARLY in 1925 the Phelps Dodge and Old Dominion Safety Organization was formed, modeled after the safety organization plan used by the U. S. Steel Corporation, and comprising (1) Phelps Dodge Corporation Safety Committee, (2) General Safety Committee at each branch; (3) Departmental Safety Committees, and (4) a Branch Safety Engineer.

The personnel of the Phelps Dodge Corporation Safety Committee consists of the general manager as chairman, and the chairman of each branch general safety committee as committeemen.

The duties of this committee are to meet once a year at each branch to discuss methods of preventing accidents, to review and analyze all condensed branch accident records, to adopt Corporation safety policies, and to discuss and plan methods for stimulating interest and cooperation in safety work. Also, at this time, the committee holds a meeting with the branch safety committee, at the property being visited, where members of both committees discuss their progress and success in accident prevention. These meetings demonstrate the sincerity on the part of the Corporation in its endeavor to eliminate accidents and tend to stimulate the branch committee to added efforts, which, in turn, are reflected to the departmental committees.

At each branch, the general safety committee consists of either the manager, assistant manager, or general superintendent as chairman, with the heads of the major operating departments and the safety engineer as committeemen. The duties of this committee are to meet at least once a month to pass on important recommendations made by the safety engineer and other committeemen, departmental safety committees, or others, to review accidents, to consider and pass on new safety devices for adoption and standardization, and to formulate plans for the furthering of interest in accident prevention.

Minutes of these meetings are furnished all committee members, as well as exchanged with other branch general safety committees. In this way, all get the benefit of the others' experience. The personnel of the branch departmental safety committee consists of the foreman of the department and from three to five workmen as committeemen; usually the safety engineer is also a member, acting as secretary. The members of this committee represent the various occupations, as far as practicable, and are periodically changed—usually after three months' service.

The chief duty of this committee is to establish sater and better working conditions for the employees in its own department, by making a study of occupational hazards and practices, and to encourage the cooperation of the workmen to report promptly for correction any existing unsafe conditions by which personal injury may result. These committees meet at least once a month, for the purpose of making a formal departmental inspection and rendering full reports of meetings with recommendations, to the chairman of the branch general safety committee.

Supplementing these committees, in some of the larger operating departments, the department head, or superintendent, as chairman, will have a standing committee of his foremen and bosses. This committee will function, in general, along the plan outlined for the branch departmental safety committee and tends to fill up the gap between the branch general safety committee and the branch departmental safety committee, so that plans and policies originating within the Phelps Dodge Corporation Safety Committee may flow through the organization to the last workman on the job.

The branch plant safety engineer has general supervision of all safety work, makes regular safety inspections of all departments, to eliminate accident hazards and dangerous practices; conducts safety educational work, investigates and studies accidents for the purpose of making recommendations to remove the cause and prevent the recurrence of similar accidents, as well as attends and participates in all meetings held to investigate accidents; attends meetings of safety committees and sees that, in general, recommendations are promptly carried out.

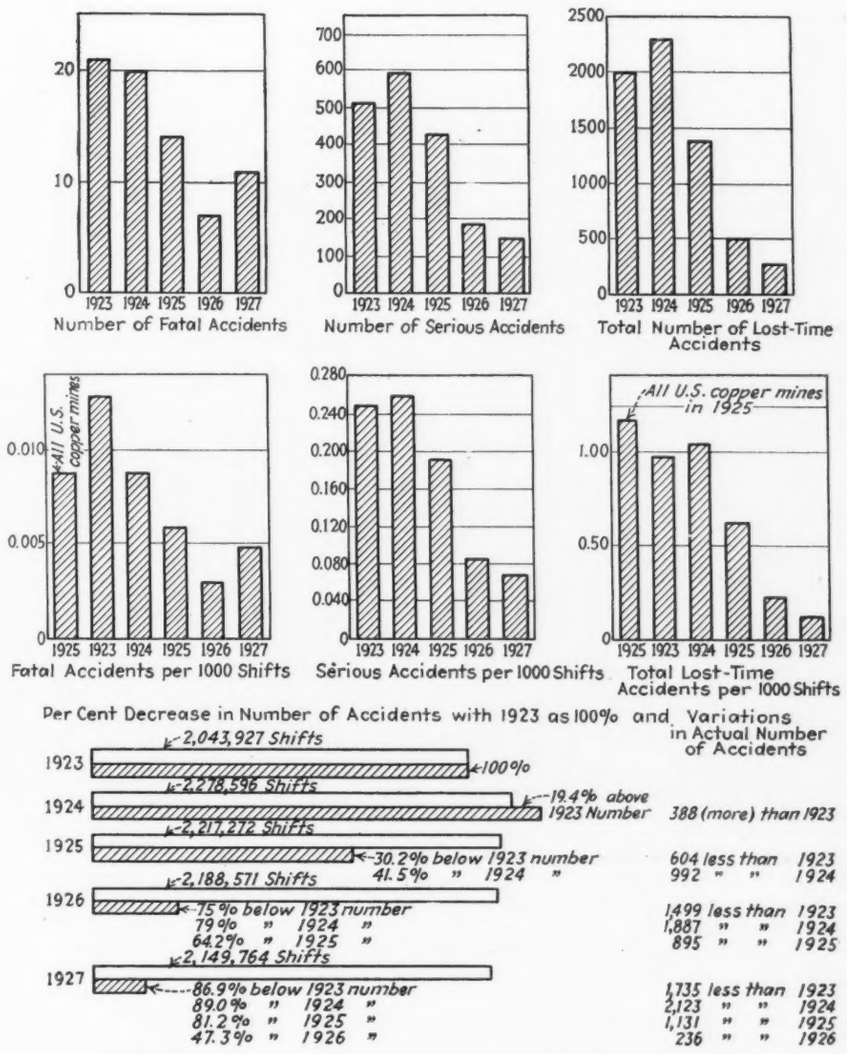
This committee plan, as described, was adopted because it was felt by the management that a strong effective organization was necessary to get a maximum number of men interested in accident prevention and away from the idea that safety was up to the safety engineer, as a one-man job.

Accident prevention is now considered at all the branches of the Phelps Dodge Corporation as a major operation, and is treated as such. The ultimate objective in mind is to carry the idea of safety to every employee of the Corporation in such a form that he will always work in a safe manner, to protect himself, as well as his fellow-workmen, from injury.

On all reports and records, only "Time Lost" accidents, which are defined as those where the injured employee is not able to report for duty on the following day, are considered. Standard forms are used in reporting each month all "Time Lost" accidents to the chairman of the Phelps Dodge Corporation Safety Committee. These forms show:

All accidents classified as to severity, responsibility, and cause. Also are reported the total shifts lost due to accidents for the month and year to date, using as a basis a schedule prepared by the International Association of Industrial Accident Boards and Commissions, for computing days lost on account of disability, as well as the number of accidents in each major operating department, with number of shifts worked and accident rate per 1,000 shifts for the month and year to date. From these data submitted to the chairman, sheets are prepared and distributed to each branch, showing current month and year to date comparisons.

The "Star Sheet," which shows the comparison of the number of accidents for the current month and year to date, as well as the accident rate in each of the major operating departments, creates a great amount of interest among the foremen and bosses, as well as among the workmen at all branches. This comparison of accidents is either posted


Number of Fatal Accidents
Number of Serious Accidents
Total Number of Lost-Time Accidents
All U.S. copper mines
Fatal Accidents per 1000 Shifts
Serious Accidents per 1000 Shifts
All U.S. copper mines in 1925
Total Lost-Time Accidents per 1000 Shifts
Per Cent Decrease in Number of Accidents with 1923 as 100% and Variations in Actual Number of Accidents
2,043,927 Shifts
100%
2,278,596 Shifts
19.4% above 1923 Number
388 (more) than 1923
2,217,272 Shifts
30.2% below 1923 number
41.5% " 1924 "
604 less than 1923
992 " " 1924
2,188,571 Shifts
75% below 1923 number
79% " 1924 "
64.2% " 1925 "
1,499 less than 1923
1,887 " " 1924
895 " " 1925
2,149,764 Shifts
86.9% below 1923 number
89.0% " 1924 "
81.2% " 1925 "
47.3% " 1926 "
1,735 less than 1923
2,123 " " 1924
1,131 " " 1925
236 " " 1926

Accident-prevention record, metal branches, 1923 to 1927

in full in conspicuous places around the plant or reprinted and sent to all employees. The results shown on this sheet form the basis for the award at the end of each year of the James Douglas Memorial Safety Trophy to that branch having the lowest accident rate per 1,000 shifts for total of all departments. This trophy carries the name of the winning branch for that year and remains on display for the ensuing year, passing on, the following year, to the next winner. There are also departmental trophies that go to the branch department having the best accident record for the year. These are distributed yearly and remain permanently with the winning department. Also, at the end of each year, that branch having the least number of days lost from disability, based on the percentage of total shifts worked, wins in the severity contest, and is awarded a trophy, which carries the name of the winning branch, to be held by them for the ensuing year, passing on to the next winner the following year. These trophies have introduced a spirit of rivalry between the branches and have greatly stimulated the general interest in the safety movement.

Very marked progress has been made in the reduction of the accident rate in the last few years, as is shown in the accompanying graph. This reduction is especially marked beginning with the year 1925, when the Committee Organization plan was adopted. In addition to the decrease in number of accidents, a great many other benefits have resulted, such as better contact between the boss and workman and a better understanding of policy, all of which is valuable in improving morale and making for a more loyal organization. Intensive safety work does not increase costs, but it is an aid to better efficiency and reduces compensation and insurance expenditures. With better contact between the management and employees on the common ground of safety, labor misunderstandings are reduced to a minimum.

On investigating what particular thing has been most effective at the various branches in obtaining the present results, all agree that the committee plan of organization has been the key. Certainly it has been through this organization that the importance of accident prevention has been emphasized to the plant superintendents, foremen, and bosses.

Tradition as to the method of doing certain work was hindering the progress of accident prevention, similar accidents were recurring, and certain classes of work continued to show a great number of accidents. To overcome these difficulties became the immediate problem of each branch committee. At one branch, excellent progress was made with the foremen and bosses in having them analyze each common operation, with the idea of adopting a standard operation that would be a safe and efficient method of doing the work. It was found that this method was superior to any other in getting the idea over to the foremen and bosses and in educating them to their safety duties and responsibilities. Furthermore, standard methods of doing the work eliminated many accident hazards to which the workman was formerly subjected.

In general, the branch managers have taken the stand that operating heads will be held responsible for safety as well as production results, it being recognized that any one in a bossing capacity not in step with the safety movement will hinder its progress.

The workmen's safety committees have been a big factor in carrying the safety idea to the workmen. Their inspection trips are especially valuable, in that criticism comes from the fellow workmen. At one branch, the duties of these committees have been expanded to cover a grading of each working place, according to the safety conditions found.

A grade marking is placed on each working place visited. In some instances poor grading is resented, but it has its effect, as it is very seldom that the same men get a poor mark on two successive inspections. After the inspection, a written report is made and a letter is written to each shift boss, calling attention to any unfavorable conditions and commending them and their workmen where good conditions are found.

At one branch, especial effort is made in accident investigation, with complete reports on each accident, followed by a careful study of the reports to see what can be done to avoid the cause. In the classification as to fault, if there is any question as to the blame of the company or the supervising force, the instructions are that they should take the responsibility for the accident. "Trade Risk" and "Employee's Carelessness" are to be used only when no other possible classification could be found. The idea in such instructions is based on the belief that if the boss was blamed for the accident, more constructive work will be done to eliminate that type of accident than if it was considered "Employee's Carelessness." This method of carefully collecting the information and analyzing each accident has been effective in reducing the number of "Lost Time" accidents.

At another branch, they have been successful in taking the safety idea to the men by giving written examinations on safety rules. These cover that part of the book containing the rules governing the class of work the man is performing.

All bosses have been required to take the examination, and in many of the operating departments all the workmen have successfully passed the examination. In others, examinations are still in progress. After a department has completed its examination, any man joining that department must successfully pass the examination within 30 days to retain his position.

In addition to the methods described, which may stand out as somewhat more important in the campaign of carrying the safety idea to the men and reducing the accident rate for the Corporation, some of the schemes used and plans adopted, more or less generally, by all the branches are as follows: (1) Proper organization and maintenance of all safety committee; (2) thorough and prompt investigation of all accidents by well-qualified persons, who are able to report the true conditions; an analysis of these accidents to determine their true cause; prompt action on the part of the management to remedy the fault, whatever it may be, to eliminate the possible recurrence of a similar accident; (3) proper inspection of operations and the correction of faulty practices which might be the source of accident; (4) careful and regular inspection of all tools and equipment; (5) extending the use of mechanical safeguards wherever possible; (6) the working out and adopting of standard practices by job analysis; the adoption of standard equipment, thoroughly proved, for safety; (8) all new construction approved as to safety; (9) careful study of compiled accident statistics to determine most common causes of accidents, then work to eliminate this class of accident; (10) the use of local photographs to show the correct method of performing work; (11) use of bulletin boards for accident record displays; (12) safety signs and slogans posted around the plant; (13) safety talks to the workmen at shaft stations, tool rooms, and working places; (14) the education of the workmen to a thorough knowledge of all safety rules; (15) education of the supervising force by foremen's and bosses' conferences; (16) letters from the management commending good safety work and results; (17) a careful study of the personnel to eliminate careless workmen; (18) a "Careless Workmen's Committee," for disciplining workmen and recommending discharge for rule violations that might cause loss of life; (19) bonus to foremen and bosses for clear accident records; (20) prizes to workmen for passing safety-rule examinations; (21) prizes to workmen for completing a definite time without suffering an accident; (22) picnics, dances, and dinners to departments for clear accident records; (23) first-aid training; (24) suggestions from workmen for improved practices, with prompt action on good suggestions and recognition of workmen by letter or prize; (25) warning letters to workmen for rule violations, with discharge for repeating offence; (26) prompt medical attention to all wounds, however slight, to avoid chances of infection.

In summing up, whatever progress has been made by the Phelps Dodge Corporation in accident prevention is not due to any great number of new ideas evolved and put into practice, but to the intense application of as many of the ideas and schemes already known and elsewhere tried out as possible, adopting one thing at a time and putting it over. From experience gained at the various branches it is evident that progress in accident prevention is only made by keeping everlastingly at it. It is essential that the management at all times take the lead and inspect operations and conditions personally.

The Phelps Dodge Corporation objective is no more "Lost Time" accidents, and it feels that the surest way to that goal is to carry safety education to every workman on the job to a point where he is a safety inspector looking out for his own as well as his fellow workman's safety and welfare. Then "Lost Time" accidents will be at a minimum.

First-Aid and Mine Rescue Work at Morenci Branch

FIRST-AID work had its beginning in the Morenci district about 1909, but did not attain any proportion until 1914, writes W. J. Williams, mine inspector. About that time, the first Bureau of Mines car came into the Clifton-Morenci district, and has frequently visited the section since then.

In 1926, about 600 men secured first or additional training from the Bureau of Mines. Supplementary to this, the Corporation has carried on its own first-aid instruction and training for contest work. Annually, an inter-department first-aid contest is held, recognized as an important feature of the safety movement. Last summer, eleven teams competed in the local contest, in addition to the regular first-aid work. All new employees in the mining department are given five lessons in elementary first aid during the first week of their employment.

The interest maintained in this work has developed some excellent first-aid men, as the records of one of the mining teams will indicate. This team placed fourth at the international contest held in San Francisco in 1926, and also won the Rocky Mountain championship and the Arizona state championship. The same team at the international meet held in Pittsburgh in 1927 was placed second, and secured the Arizona State championship for the second time. This measure of success in competition has stimulated the interest of men in all departments for first aid.

Mine rescue work was taken up in the district in 1914, using at that time the Draeger apparatus and later the Fluess-Proto. Eleven sets of Gibbs apparatus are now in use. Early in 1927, a modern fire-proof mine rescue station was completed, the main building being 51 ft. 4 in. long and 15 ft. 10 in. wide. This is divided into three rooms. The main room is used for first aid and instruction. The two M.S.A. high-pressure oxygen pumps are also in this room. At the south end of the building is the gas room, in which the apparatus is tested. The office occupies the other half of this end of the building.

Owing to the dryness of the climate, and the consequent rapid deterioration of all rubber goods, it was necessary to build a vault projecting from the west wall of the building, in which to store the apparatus. The vault has a capacity of fifteen sets of apparatus, over which is the testing bench. Each set of apparatus is kept in its individual box, complete with wrenches, flashlight, goggles, and one M.S.A. self-rescuer.

An adequate supply of "cardoxide" and repair parts for the apparatus is carried in the station, as well as two sets of all service gas masks; a carbon monoxide detector, in addition to canaries for testing poisonous atmosphere; a pyrotanic detector for the rapid determination of carbon monoxide in the blood and air; an Orsatt apparatus for the analysis of gases in mine air; an impinger for collecting dust samples; and a konimeter for qualitative estimates of dust in connection with mine ventilation.

How a Tailing Disposal Dam Is Built

FOR the distribution of tailing at Morenci Branch, as described by Arthur Crowfoot and Dale C. Barnard, superintendent and assistant superintendent, respectively, a fence 24-in. high (two 12-in. planks) is set up across the top of the dam. Every 10 ft. a 2x6-in. stake is driven in to support the fence. Stakes extend 2 ft. above the top of the planks to support a hanger for the tailing distributing pipe. Knee braces (2x4 in.) are placed back of the fence to hold it in a vertical position. The pipe for distributing the tailing is 8 in. diameter, of smooth "Armco" galvanized iron, in 20-ft. lengths, riveted but not soldered.

Holes are burned in the under side of the pipe $1\frac{1}{4}$ in diameter every 5 ft. for discharge of the tailing onto the dam. Similar holes are placed on the upper side of the pipe for the release of entrained air.

The pipe, as installed, is about 3 ft. above the bottom of the fence and is supported by an iron bracket made to fit over extended ends of the 2x6-in. stakes. These brackets are adjusted as to height, and the pipe is carried on a grade of $\frac{3}{8}$ in. per foot across the dam.

The cycle of operation is: Running on dam, 4 to 6 days; drying and moving fence, 12 days. The fence is moved forward 2 ft. with each raise of 18 in. on the dam. Corrugated galvanized 8 in. iron pipe is used for drainage under the dam.

Inventory Control

By J. L. Hastings

General Purchasing Agent

THE YEARS following the close of the World War found almost every industry in the country carrying tremendous inventories of warehouse materials. In this the copper-mining companies of the Southwest were no exceptions: In fact, because of greater distance from the principal manufacturing centers, their inventories were probably larger than the average. After the shutdown in 1920, strenuous efforts were made to reduce stocks, and those efforts have continued to this time.

In analyzing inventories many instances were found of materials with sometimes only slight differences, used in the same application at different units. To cite an example: Some plants used bolts fitted with H.P. nuts; others used bolts with C.P. nuts. Some wanted bolts with hexagonal nuts; others wanted square nuts. These differences made it difficult to transfer surplus stocks from one point to another. It was soon realized that there should be less variety in warehouse stocks; that the more uniformity, the more flexibility. Therefore, an effort was made to simplify stocks, or to reduce as far as possible the different sizes, types and styles.

When supplies are not interchangeable, they turn slowly. Simplified practice in the selection of warehouse materials means: less money tied up in inventory, less storage space, less idle equipment, less obsolete materials, less slow moving stocks, better turnover, better quality of product, better efficiency of clerical force, better stock control.

Simplification in warehouse stocks assures reduction in variety of sizes, many of which vary so little that the differences are immaterial. Eliminating unnecessary items cuts costs and increases consumption of those remaining in active stock, without impairing the efficiency of operating departments. In the last few years the government has co-operated with a large number of industries in eliminating unnecessary variety, with saving of millions of dollars annually in reduction of stocks, lowered manufacturing costs, and increased buying power.

In analyzing the causes of waste, the federal authorities estimated that, based on 1922 prices, approximately ten billion dollars in that year might have been saved by proper simplification and standardization. This sum would have paid all the federal, state, and municipal taxes, would have paid for all the homes built in the United States, for the passenger automobiles purchased that year, and for the gasoline to run them.

The simplification of grades, sizes, and performances, and standardization of quality, have already resulted in a remarkable reduction of waste, and yet the work of simplifying manufacture to reduce unnecessary sizes is still in its infancy. Although much of the work in simplification has been directed toward elimination of waste in manufacture, it has its effect upon the user, as such simplification reduces manufacturing, selling, and distribution costs, releasing millions tied up in slow-moving stocks, and finally reaching the consumer in lower prices.

To take one example—lamp bases. Only a few years ago there were 179 varieties of lamp bases. Today 70 manufacturers are producing six standard bases. In the same industry there were 37 varieties of attachment plugs. Today there is one standard plug. The tremendous saving to manufacturers, distributors, and consumers is apparent.

Although simplification in manufacture benefits the user in lowered costs, the examples set by manufacturers can be followed by individual companies in eliminating waste in their own operations wherever it can be found, such as unnecessary sizes, varieties, and styles. Much can be accomplished by close and earnest co-operation on the part of the supply departments and the various operating heads. Covering the ground once is not enough. Going over it again and again with the same operating heads will disclose new opportunities for reducing sizes and varieties. As some one once said: "Why buy 15 sizes of bolts if you can, by study, make one kind of bolt satisfy the 15 uses?" This theory is being worked out in all our branches with good results.

The accompanying table is a record of reduction accomplished in one of our branch warehouses, according to its report submitted June 24, 1927.

A study of conditions will disclose many interchangeable parts, which means that the duplicate item is eliminated from stock. Ordinary machine bolts have been found to answer for special bolts, and the latter eliminated. Items have been ordered in the past by heads of departments on the theory that they "might be needed." Many of these have been discontinued when stock on hand was exhausted and reordered only when actually required.

In one branch, a complete list of stock on hand, cost, and consumption for one year was sent to the heads of each department, with request that they check all items used regularly. When the lists came back to the supply department manager, he called a conference of all department heads; all items were carefully gone over, and a list was made of all items that could be eliminated. When the stock of those items was exhausted no more was ordered.

The procedure mentioned in the pre-

Table I—Simplification of Stocks

Commodity	Number of Items		
	Formerly	Now	Reduction, per Cent
Air drills and parts	534	302	43
All cars and repairs	347	138	60
Steam locomotives and repairs	192	55	71
Electric locomotives and repairs	176	99	43
Steam shovels, churn drills, and cranes	908	295	67
Brass and iron castings	199	125	37
Electric materials	643	476	26
Bolts, screws, rivets and nails	1,752	1,297	26
Packing and waste	434	275	36
Tools of all kinds	507	395	22

ceding paragraph demands hearty co-operation between the supply department manager and heads of departments. In most instances the supply department manager has initiated the movement and sold the idea to the others. If this plan is followed through, and the interest not allowed to lag, most interesting results will follow.

Our different branches submit, at the end of each year, a report showing in percentages the reduction or increase of all classes of materials carried in inventory. It is notable that each year shows large reductions and few increases of any class. Even during 1927, or after several years of effort, the various warehouse departments made a most satisfactory showing, and the end is by no means in sight. The whole question of simplification of warehouse stocks is of utmost importance. We are "sold" on the idea and urge it upon our various departments as a means of reducing costs.

Closely coupled with simplification is standardization. The development of standards of material, of equipment, and of performance is a significant phase of present-day management. Without such standards, operating costs are high. Today many corporations are carrying on standardization work in their individual operations. The General Motors Company is a leading example. It has an efficient standards committee and is proud of its accomplishments, much of its prosperity being the result of savings made possible by standardization. Probably many of the individuals in that corporation have had to be talked into accepting the corporation's standards, but because those individuals have suffered no inconvenience and have enjoyed an improvement in quality or a lower price, they have been willing to accept such standards.

Standardization is simply the selection of a material which has proven its worth—a survival of the fittest. It must be the best that can be secured for the purpose required, and can remain as a standard only until something better takes its place. No form of standardization should be so rigid as to make revision impossible.

Centering on fewer varieties, the purchasing department is in better position to keep in touch with market conditions, to place larger and fewer orders, and, as a result, to secure lower prices and better discounts. Any company in position to consolidate requirements, regulate distribution of reserve stocks, and readily transfer surplus stocks at one point to supply shortage at another point, can exert maximum buying power.

To cite an example of the advantages of standardization: After long tests with several makes of drill steel, the one proving most satisfactory—service and cost considered—was selected as a standard, and a contract entered into. Orders are placed in carload lots, sometimes for straight carload shipments to one branch; at other times a carload is distributed among several branches. In this way the maximum saving in cost is secured—first, by a contract covering our entire requirements; second, by shipment in carloads from mill for distribution to different mines as required. Without a standard, acceptable to all our operations, such an advantageous arrangement would be impossible, buying power would be scattered, and purchases would be made from various sources in small quantities, with resulting higher costs.

To be worth while, tests of materials must be complete and conclusive. Often they are expensive and take considerable time. Therefore, it has been found advantageous, when a test was advisable, to have it made at one branch only for the benefit of all branches, and all to share in the expense of conducting the test. When that test has been completed and the most satisfactory material found, requirements are covered and that subject is closed until such time as another test, conducted in the same manner, is advisable. In this way, haphazard tests are avoided, and important items are standardized, resulting, we believe, in a higher average of quality and a lower average of cost.

Besides standardizing materials, many operations have been standardized throughout the Corporation, by means of exchanging reports between branches, these having to do with new methods tried, results from the use of new equipment; in fact, any items of general interest that might be an aid to other branches. This is a matter that our management has strongly favored, and results have been very satisfactory.

So closely connected with standardization as to be at times almost indistinguishable is the buying of materials to specifications. The quarrel between quality and price is settled when buying is done on well-prepared specifications. If the quality is too good, the price in the comparison of bids will eliminate it. If the quality is too poor, the standard set by the specification will eliminate it. As a result, the bid accepted may not be the highest or the lowest in price, but it will represent the truest economy to the buyer, provided the specification has been well formulated. Improper standards established through selection of materials because they are highly advertised, or because of pressure brought to bear by representatives of the seller, have cost many concerns tremendous sums annually.

The federal government, through the activity of the Federal Specification Board, has recently given great impetus to the increased use of specifications. It has co-operated with engineering societies, university laboratories, and great industrial laboratories in developing specifications covering a multitude of materials. It has issued a directory of specifications of immense value. To quote from the foreword of this directory:

"The direct purpose of any wise co-operated effort in the adoption of specifications is to secure constructive adoption of scientific knowledge to service requirements; to co-ordinate similar demands and eliminate unnecessary differences; to balance increases of cost against proper service improvement, all resulting in the development of greatly improved products, marked lowering of costs and prices."

The attempt to purchase to specifications calls for pioneer work. Often prejudices and opposition must be overcome, but the benefits of standards are realized, and more industries are becoming alive to their value. The benefits to the user, where standard specifications have been in vogue for any length of time, are well understood and acknowledged. To quote again relative to the benefits to the user:

"1. He can secure truly competitive bids on the same quality of material—a condition greatly to his advantage. Truly competitive bidding under a quality specification is welcomed by the progressive manufacturer.

"2. The details of purchasing are simplified and standardized—a matter of especial importance in large organizations.

"3. Standard methods of test and inspection are of particular value in establishing a routine procedure for acceptance of material.

"4. The greater uniformity and reliability of material purchased unde standard specifications, and the fact that its properties are more thoroughly understood, make possible its more economic use."

Carefully developed specifications, covering almost every material required, are available and may be secured from such organizations as the Federal Specifications Board and the American Society for Testing Materials, as well as the railroads and large industrial corporations.

We have only begun to realize the importance of the three economic movements described above and of the financial benefits which accrue in the way of reduced capital investment, less depreciation and obsolescence, quicker turnover, and smaller inventory. The story of whole-hearted co-operation on the part of all departments in the use of materials bought to specifications and in the elimination of waste through simplification and standardization is best told in the comparison given below of the Phelps Dodge and Old Dominion inventories for the years ending 1920 and 1927:

Total inventory Dec. 31, 1920..	$4,592,915.66
Total inventory Dec. 31, 1927..	1,937,532.00
Reduction	$2,655,383.66

It is, of course, recognized that simplification, standardization, and buying to specifications have not been the only factors in this inventory reduction, but a close study of conditions reveals that they have had a most marked effect on inventories, and that their influence will undoubtedly be felt even more in the future than in the past.

How to Classify Ground for Bonus Payments

IN 1915, the Copper Queen Branch, during preliminary investigation of contract and bonus systems, found that the first essential was a method of classifying the ground as to drilling and breaking qualities, states F. H. Hayes, mine superintendent. It was decided to select untimbered drifts as a starting place in this work. In the beginning, the ground was roughly classified according to one degree of penetration of a hard-pointed steel when hit a certain blow. This led to the development of a small stoper-type machine, light enough to be carried through the mine. This machine was calibrated in the machine shop by means of a new standard stoper, and the various kinds of ground in the mine were then drilled. After a great number of tests had been made, a curve was plotted from which classes of ground were selected corresponding to various drilling speeds. For some time thereafter this machine was used in all divisions of the mine for classifying ground. At the end of the period the experience gained by actual work and comparison of records led to the following classification for all prospect drifts:

Class of Ground	Drilling Speed in Inches per Minute
A +	1½ to 2
A	2 to 2¾
A —	2¾ to 3¾
B +	3¾ to 5
B	5 to 6½
B —	6½ to 8¼
C +	8¼ to 10½
C	10½ to 12½
C —	12½ to 15

The determining factors were drilling speed and breaking qualities of the rock. The former was at first found by timing the drilling, this being done by counting the number of turns of the crank per minute of the machine. Factors such as type and condition of machine and air pressure had to be considered. In later years, experience gained has made this unnecessary except in rare instances.

Breaking qualities are determined by noting whether the face has well-defined slips or seams, and in what direction they run, and whether the ground is blocky limestone, porphyry, or massive sulphide. If it is fast drilling but poor breaking, it is marked up one or two classes, according to the judgment of the classification man. If the reverse is true, the class is dropped. In untimbered drifts, more than 95 per cent of the footage falls in the classes from *A* to *C*. In timbered drifts, *B*— to *C*+ apply to most conditions. The same procedure applies to raises.

In stoping, the drilling time being a smaller percentage of total time than in drifts and raises, only three classes of ground are used: *A*, *B*, and *C*. These do not bear any relation to drift classifications. Hard, massive sulphide or very hard siliceous oxidized ores are classified as *A* ground. The high percentage of stoping, however, lies within the middle class.

In the porphyry mine, three classes are used: Hard, intermediate, and soft, abbreviated to *H*, *I*, and *S*. Here the ground is much more uniform both as to drilling speed and breaking qualities, and experience has shown that two classes would probably cover all conditions.

Many Eyes Saved by Goggles at Morenci Branch

	1926	1927
One lens shattered by flying metal.....	4	7
One lens spattered by molten metal.....	1	0
Both lenses spattered by molten metal....	0	1
One lens shattered by other flying objects	3	12

Portable Assay Office Facilitates Routing of Raw Material

IN STEAM shoveling the Sacramento Hill deposit, writes S. G. Plummer, superintendent, the extremely variable copper content makes it necessary to separate the material into classes for most economical subsequent treatment. Ore containing over 6 per cent copper is sent to smelter bins, ore between 0.80 and 6 per cent to the concentrator, material from 0.30 to 0.80 per cent to leach dumps, and material below 0.30 per cent to waste heaps. With the destinations of each class of ore only a mile from the pit, and as many as seven shovels working, it is necessary to know the grade of the material as soon as possible.

To facilitate rapid returns on samples, a portable assay office was built on two discarded flat cars, the pulverizing room on one and the chemical laboratory on the other. As mining progresses, the car can be moved to locations convenient to shovel operations.

The pulverizing car is equipped with a 5x8-in. jaw crusher, through which the sample first passes and is crushed to ½-in. mesh; it then passes through 10-in. rolls and is crushed to ⅛-in. mesh. It is then put through a splitter, which reduces it to the amount taken to the laboratory, being first dried on an electric hot plate, and then passed through a pulverizer. The machinery is driven by a 10-hp. motor. An exhaust fan removes dust from the room.

All determinations for copper in the laboratory are made by the colorimetric method. The cost of sampling and assaying is 0.412c. per ton.

As soon as the copper contents in the train are known, its disposition is telephoned to the dispatcher, who routes it accordingly, to the proper destination. The total elapsed time after the sample reaches the pulverizing car is from five to six minutes, which causes no delay to mining operations.

Nail Straightener Effects Economies at the Pilares Mine

AT THE Pilares mine of the Moctezuma Copper Company a great deal of salvaging is done. For example, old bent nails recovered at the concentrator are sent back to the mine to be reconditioned. The apparatus used consists of an old Waugh "93" drilling machine mounted on a stand. The ratchet of the rotation and the front head were removed, and a pipe guard was substituted for the latter. In operating the device, the hammer strikes on a grooved anvil, the groove being semicircular and roughly of the same diameter of the nail.

The nails are held one at a time with a pair of tongs, subjected to the blows of the hammer and at the same time rotated. When extreme bending is necessary, the nails are first roughly straightened by hand by inserting them in a slot cut in an iron plate, and are then placed under the air hammer. An average of 50 kilos of nails per shift is reclaimed. Considering the cost of labor and air involved in the operation, a moderate saving is effected in comparison with the cost of new nails.

Diamond Drilling Proves Valuable Underground

APPROXIMATELY 1,400 ft. of diamond drilling per month is done at Pilares. This may be divided into wall and core exploration, and stope drilling. Wall and core exploration holes, generally long holes, are drilled in unprospected areas. If ore is encountered, there is an objective to drifting or raising; if not, much labor and money is saved.

Stope drilling constitutes approximately 60 per cent of all drilling. Because of the irregular nature of the orebodies, it is often advisable to prospect beyond the assay limit of the ore. Consequently, to prevent leaving ore behind, when a stope has silled as far as is economically possible, short holes are drilled out at the most favorable points if the geological conditions warrant. This drilling has proved exceedingly satisfactory. Stopes are also drilled to prove the extent and grade of the orebody, preparatory to deciding the best method of mining the ore.

Old Hoisting Cable Serves as Conductor

THE UNDERGROUND trolley hauls at the Old Dominion mine are long, and conditions are such that it is difficult to maintain the proper bonding of rails, states Charles Mendelsohn, mechanical superintendent. This results in a large drop in voltage toward the ends of the lines. As an attempt to remedy this condition, old 1¼-in. hoisting cable was laid along the haulage drifts and bonded to the rails at intervals of about 150 ft. This has been of considerable help and has decreased the voltage drop appreciably.

The Market Report

Copper Price Advanced to 15½c.

Fair Demand for Other Metals as Fabricators Clamor for Copper

New York, Oct. 24, 1928—Copper, which has occupied the center of the non-ferrous-metal market stage so much in recent months, returned to a dominating position during the week ending today, which followed several weeks of subnormal buying earlier this month. With export business again in large volume, and domestic consumers begging for the metal for any delivery, an advance in price to 15½c. per pound has been recorded. Lead buying continued in slightly better than average volume at unchanged prices. Zinc is firm at 6.25c. per pound, East St. Louis, with more interest and buying by galvanizers. Tin ended the week with little net change, following a mid-week spurt.

Daily Prices of Metals

Oct.	Electrolytic Copper	Straits Tin	Lead		Zinc
	Refinery	New York	New York	St. Louis	St. Louis
18	15.00@15.05	49.00	6.50	6.325	6.25
19	15.025	49.50	6.50	6.325	6.25
20	15.25	49 375	6.50	6.30	6.25
22	15.275	49.25	6.50	6.325	6.25
23	15.275	48.75	6.50	6.325	6.25
24	15.275	48.50	6.50	6.325	6.25
	15.188	49.063	6.500	6.321	6.250

Average prices for calendar week ending October 20, 1928, are: Copper, 15.063; Straits tin, 48.938; N. Y. lead, 6.500; St. Louis lead, 6.315; zinc, 6.248; and silver, 58.000.

The above quotations are our appraisal of the major markets for domestic consumption based on sales reported by producers and agencies. They are reduced to the basis of cash, New York or St. Louis, as noted. All prices are in cents per pound.

Copper, lead, and zinc quotations are based on sales for both prompt and future deliveries; tin quotations are for prompt delivery only.

In the trade, copper prices usually are quoted on a delivered basis: that is, delivered at consumer's plant. As delivery and interest charges vary with the destination, the figures shown above are net prices at refineries on the Atlantic seaboard. Delivered prices in New England average 0.225c. per pound above those quoted.

Quotations for copper are for the ordinary form of wire bars and ingot bars. For ingots an extra 0.05c. per pound is charged; for slabs, 0.075c.; and for cakes, 0.125c. up, depending on weight. Cathodes are sold at a discount of 0.125c. per pound.

Quotations for zinc are for ordinary Prime Western brands. Zinc in New York is now quoted at 0.35c. per pound above St. Louis, this being the freight rate between the two points.

Quotations for lead reflect prices obtained for common lead, and do not include grades on which a premium is asked.

London

Oct.	Copper			Tin		Lead		Zinc	
	Standard		Electrolytic	Spot	3M	Spot	3M	Spot	3M
	Spot	3M							
18	65 1/16	65 9/16	71¼	222¼	219¾	22⅛	21 13/16	24⅛	24⅜
19	65 7/16	65 15/16	71¼	224⅜	222½	22 3/16	21⅞	24 1/16	24 5/16
22	65 15/16	66 7/16	71½	224⅞	222¾	22⅛	21¾	24⅛	24 5/16
23	66	66½	72¼	222¼	220⅛	22 3/16	21 13/16	24 1/16	24 5/16
24	66 5/16	66 13/16	72¼	220½	219⅜	22⅛	21¾	24	24¼

The above table gives the closing quotations on the London Metal Exchange. All prices in pounds sterling per ton of 2,240 lb.

Silver, Gold, and Sterling Exchange

Oct.	Sterling Exchange "Checks"	Silver		Gold London	Oct.	Sterling Exchange "Checks"	Silver		Gold London
		New York	London				New York	London	
18	4.84 5/8	58	26 11/16	84s11½d	22	4.84½	57¾	26 9/16	84s11½d
19	4.84 9/16	58	26 9/16	84s11½d	23	4.84 9/16	57⅞	26 11/16	84s11½d
20	4.84 9/16	57⅞	26⅝	.....	24	4.84⅝	58	26 11/16	84s11½d
					Ave.		57.917		

New York quotations are as reported by Handy & Harman and are in cents per troy ounce of bar silver, 999 fine. London silver quotations are in pence per troy ounce of sterling silver, 925 fine. Sterling quotations represent the demand market in the forenoon. Cables command three-eighths cent premium.

Copper Scarce, but Inquiries Continue at Higher Prices

The so-called buying waves in copper appear to be merging into one of the "tidal" variety judging by the volume of copper sold during the week ending today. That this week marks the beginning of any such buying activity as took place in the September record-breaking drive is unlikely—primarily because the sustenance for such buying activity is lacking. Domestic sales were over 300 per cent of normal, and export sales are keeping up closely with the daily average for September. In view of these circumstances, the advance in price is not without justification—in fact it is surprising that a larger advance has not been recorded when the sellers' position previous to this latest buying demand is considered. Sales on Friday were particularly heavy, and on Saturday the price was advanced from 15¼c. to 15½c. per pound by most producers, though some metal changed hands at the lower level, as is reflected in the quotation for that day. The last of the 15¼c. metal was not absorbed until Monday, though large sales in the Middle West at the usual premium over the Connecticut Valley basis offset the small tonnage at that level. Copper Exporters, Inc., advanced their price to 15¾c. per pound c.i.f. usual European destinations on Tuesday, Oct. 23. A large proportion of the week's transactions has been for January delivery. At least one sale for February-March delivery has been consummated.

Lead Market Steady

The situation in the lead market is almost entirely unchanged from what it has been in the last two or three weeks. A slightly larger volume of sales was registered this week over last, though the market cannot be characterized as particularly active, a few big sales taking the place of more numerous orders for small lots. The price in the East remains at the American Smelting & Refining Company's contract level of 6½c., though where chemical lead is required, a premium of 5 or 10 points must be paid. In the Middle West, also, the position of producers is unchanged, with small offerings of spot lead at 6.30c. in one or two directions, and the larger sellers realizing 6.325c. for either prompt or November deliveries. A fair amount of lead has been sold in both the Middle West and the East, for December shipment, also.

Ammunition manufacturers have been conspicuously in the market this week, taking heavy tonnages in individual sales. Battery and cable manufacturers have also been well represented, but corroders have shown little interest.

Zinc More Active; Price Firm

Sales of Prime Western zinc have been in appreciably larger volume dur-

ing the week ending today, though the total is not a staggering figure by any means. Price remains unchanged at 6.25c. per pound East St. Louis. Recent statistics from the Tri-State district are most unfavorable, but a late report to the effect that the five-day week has been adopted by 80 per cent of the operators and is now in effect should soon be reflected in the statistical figures.

No Dearth of Spot Tin

The tin market strengthened a little three or four days ago, but has since declined to about the level that obtained last week. Ample arrivals, both here and in London, have resulted in the price of spot declining to that for futures; in fact, today it was said that spot could be bought at ⅛c. below futures. Consumers picked up numerous cheap offerings yesterday, but, in general, the week has been a quiet one, without many sales of importance either to consumers or dealers. There is practically no 99 per cent tin on the market.

Silver Dull and Inactive

No change in the silver market is to be recorded in the last week, and prices fluctuated within narrow limits. Reports from abroad state that both China and India were buyers there, and occasional orders were received here for China account. As prices are slightly above Indian parities, no orders were received from that source. The market is dull and inactive.

Mexican Dollars (Old Mexican pesos): Oct. 18th and 19th, 43⅞c.; 20th, 43⅜c.; 22d, 43⅝c.; 23d, 43¼c.; 24th, 43⅞c.

Foreign Exchanges Stronger

Closing cable quotations on the principal foreign exchanges on Tuesday, Oct. 23, were as follows: Francs, 3.90$\frac{3}{16}$c.; lire, 5.23$\frac{15}{16}$c.; and marks, 23.825c. Canadian dollars, $\frac{1}{32}$ per cent discount.

Other Metals

Quotations cover large wholesale lots unless otherwise specified

ALUMINUM—Per lb., 99 per cent plus grades, price of leading interest, 24.30c. Outside market, 99 per cent plus, 24.30c.; 98-99 per cent, 23.90c.

ANTIMONY—Per lb., duty paid, New York: Chinese brands, 10½c. per lb. for spot, 10¼@10c. per lb. for futures. Cookson's "C" grade, spot, 15⅜c.

BISMUTH—Per lb., New York, in ton lots, $1.70. Smaller lots, $1.85 and up.

CADMIUM — Per lb., New York: 70@95c.

IRIDIUM — Per oz., $280@$300 for 98@99 per cent sponge and powder.

NICKEL—Per lb. ingot, 35c.; shot, 36c.; electrolytic, 37c. (99.9 per cent grade) for single lots of spot metal.

PALLADIUM — Per oz., $42@$46. Small lots bring up to $50. Nominal.

PLATINUM—Official price quoted by the leading interest on small miscellaneous orders for refined metal, per oz., $78. Dealers and refiners quote the trade for refined metal, per oz., cash, for wholesale lots, $73.50@$74 bid, $75@$76 asked. Quiet.

QUICKSILVER — Per 76-lb. flask, $125@$127, cash. Small lots command the usual premiums. San Francisco wires $128.33.

Prices of Cobalt, Germanium Oxide, Lithium, Magnesium, Molybdenum, Osmium, Radium, Rhodium, Ruthenium, Selenium, Tantalum, Tellurium, Thallium, Tungsten, and Zirconium are unchanged from the issue of Oct. 6.

Metallic Ores

TUNGSTEN ORE—Per unit of WO_3, N. Y.; Wolframite, $10.90@$11; Western scheelite, $11.50. Nominal.

Chrome, Iron, Manganese, Tantalum, and Titanium ores are unchanged from quotations in the Oct. 6 issue.

Five-Day Week in the Tri-State

Joplin, Mo., Oct. 20, 1928

Blende	Per Ton
High	$43.20
Premium blende, basis 60 per cent zinc	$40.00@ 41.00
Prime Western, basis 60 per cent zinc	39.00@ 40.00
Fines and slimes, 60 per cent zinc	36.00@ 38.00
Average settling price, all zinc	40.12
Galena	
High	$86.20
Basis 80 per cent lead	85.00
Average settling price, all lead	84.15

Shipments for the week: Blende, 10,542; lead, 2,791 tons. Value, all ores the week $557,820.

Operation on a five-day week basis was begun today by a number of the more prominent mine owners. If a sufficient number join it is proposed to continue operating thus for the rest of the year. The test is not alone upon the number of mines that will take part, but involves the number of hours worked per week, as one other movement was started on a five-day week but a number of operators changed from an eight- to a ten-hour day, and produced more ore in five than had been produced in six days previously.

Movement of lead stocks continues at the rate of 400 to 500 tons per week more than the production, sellers assuming that the price is as high as it will go. It is remembered that a slump in lead prices occurred in the fall of 1927.

Platteville, Wis., Oct. 13, 1928

Zinc Blende	Per Ton
Blende, basic 60 per cent	$42.75
Lead Ore	
Lead, basis 80 per cent	$86.00

Shipments for the week: Blende, 922 tons; lead, none. To separating plants, 1,404 tons blende.

Platteville, Wis., Oct. 20, 1928

Zinc Blende	Per Ton
Blende, basis 60 per cent	$42.75
Lead Ore	
Lead, basis 80 per cent	$86.00

Shipments for the week: Blende, 703 tons; lead, none. Shipments for the year: Blende, 30,349 tons; lead, 1,570 tons. Shipments for the week to separating plants, 1,285 tons blende.

Non-Metallic Minerals

Amblygonite, Asbestos, Barytes, Bauxite, Borax, Celestite, Chalk, China Clay, Diatomite, Emery, Feldspar, Fluorspar, Fuller's Earth, Garnet, Gilsonite, Graphite, Greensand, Gypsum, Iron Oxide, Lepidolite, Limestone, Magnesite, Mica, Monazite, Ocher, Phosphate, Potash, Pumice, Pyrites, Quartz Rock Crystal, Silica, Spodumene, Sulphur, Talc, and Tripoli are unchanged from prices in the Oct. 6 issue.

Metallic Compounds

ARSENIOUS OXIDE (White Arsenic) Per lb., 4c. Quieter.

Antimony Oxide, Calcium Molybdate, Copper Sulphate, Sodium Sulphate (Salt Cake), Sodium Nitrate, and Zinc Oxide are unchanged from prices in the Oct. 6 issue.

Alloys

FERROMANGANESE—Per long ton, domestic and foreign, f.o.b. furnace or duty paid, port of entry, $105 quoted for last half, 1928. Spiegeleisen, 19@21 per cent, $33 f.o.b. furnace.

Ferrocerium, Ferrochrome, Ferromolybdenum, Ferrophosphorus, Ferrosilicon. Ferrotitanium, Ferrotungsten, Ferrovanadium and Monel Metal are unchanged from prices in the Oct. 6 issue.

NICKEL SILVER — Price for 18 per cent Grade A sheets advanced from 30¼ to 30½c. per lb., effective Oct. 20.

YELLOW (MUNTZ) METAL—Price for dimension sheets advanced from 20¾ to 21c. per lb.; for rods, advanced to 18c. from 17¾c. per lb.; effective Oct. 20.

Rolled Metals

COPPER—Price for sheets, hot rolled, advanced from 24 to 24¼c. per lb.; for wire advanced from 17⅛ to 17⅜c. per lb. Oct. 20.

Lead and Zinc Sheets are unchanged from prices in the Oct. 6 issue.

Refractories

Chrome Brick, Fireclay Brick, Magnesite Brick, Silica Brick and Zirkite are unchanged from quotations in the issue of Oct. 6.

Iron, Steel, and Coke

Iron—Per gross ton, Valley furnaces, Bessemer, $18; basic, $17; No. 2 foundry, $17@$17.50.

Steel—Base prices per gross ton, Pittsburgh, billets and slabs, $33@$34; plates, structural shapes, and soft steel bars, per lb., 1.90@2c.

Coke — Per gross ton, Connellsville furnace, $2.85@$3. Connellsville foundry, $3.75@$4.85. By-product coke, Ohio and Kentucky, $7; Buffalo and Detroit, $8.50@$9.

Mining Stocks—Week Ended October 20, 1928

Stock	Exch.	High	Low	Last		Last Div.
COPPER						
Anaconda	New York	87½	82½	87	Oc.13, No. 19 Q	1.00
Ariz. Com'l	Boston	5	4½	4¾	Jl. 16, Jl. 31 SA	0.25
Cal. & Ariz	New York	118	113	114¾	Se. 7, Se. 24 Q	1.50
Calumet & Hecla	Boston	46	33½	42½	No. 30, De.15,Q	1.00
Cerro de Pasco	New York	103⅜	95½	102½	Oc.11, No. 1 Q	1.25
Chile Copper	New York	59⅜	51½	57½	Se.15 Se.29 Q	0.62½
Con. Coppermines	N. Y. Curb	12¾	12	12½		
Copper Range	Boston	24	20¾	22¾	Mr. 24, Ap. 20 A	1.00
Crystal Copper	Boston Curb	*25	*22	*25		
East Butte	Boston	3½	3	3¼	Dec., 1919	0.50
Granby Consol	New York	72⅜	64⅜	69½	Oc.11, No.1 Q	1.00
Greene Cananea	New York	134⅜	126	130⅞	Se. 14, Oc.1 Q	1.00
Howe Sound	New York	67½	64	66½	Se.29, Oc.15, Q	1.00
Inspiration Consol	New York	31½	28⅜	30½	Apr. 1927 Q	0.25
Isle Royale	Boston	25⅜	20⅜	24½	Au.31, Se.15SA	X0.75
Kennecott	New York	113	103⅜	111½	Au.31, Oc 1 Q	1.50
Magma Copper	New York	59⅜	57⅜	59⅜	Oc.1, Oc.15 Q	0.75
Mason Valley	N. Y. Curb	1⅜	1¼	1⅜		
Miami Copper	New York	24½	22½	24	No.1, No.15, Q	0.37½
Mohawk	Boston	52⅞	50	50⅜	Oc. 31, De. 1 Q	3.00
Montana-Idaho	Spokane	*13⅜	*12½	*13⅜		
Mother Lode Coal	New York	3½	3½	3½	Je.8, Je. 30, SA	0.15
Nevada Consol	New York	29½	27½	29⅜	Se.14, Se.29 Q	0.37½
New Cornelia	Boston	34	32½	34	Au.3, Au. 20 Q	0.50
Noranda	N. Y. Curb	55½	46⅜	55½		
North Butte	Boston	5	3⅞	4⅛	Oct., 1918	0.25
Ohio Copper	N. Y. Curb	*79	*70	*73	Sept., 1926	0.03
Old Dominion	Boston	16	14⅜	15	Dec., 1918	1.00
Phelps Dodge	N. Y. Curb	199½	195	198½	Se.10, Oc.1 Q	2.00
Quincy	Boston	45	41½	45	March, 1920	1.00
St. Mary's Min. Ld	Boston	35	31½	33½	Ap.1928 A	2.00
Seneca Copper	New York	5½	4½	5⅜		
Shattuck-Denn	N. Y. Curb	18⅞	17½	18		
Tenn. C. & C	New York	16½	15⅝	15⅞	Au., 31 Se.15,Q	0.25
United Verde Ex	N. Y. Curb	21⅞	17⅝	20⅜	Oc.6, No.1 Q	0.50
Utah Copper	New York	190	183	190	Se.14, Se.29 Q	2.00
Utah Metal & T	Boston	1⅜	1¼	1⅜	Dec., 1917	0.30
Walker Mining	Salt Lake	1.80	1.72½	1.80		
NICKEL-COPPER						
Internat. Nickel	New York	190	145½	179¼	Se.10, Se.29 Q	0.75
Internat. Nickel pfd	New York	122	122	122	Oc.1, No.1 Q	1.50
LEAD						
Gladstone Mtn	Spokane	*5½	*4⅜	*5	June, 1927	0.005
National Lead	New York	122⅞	120	122⅜	Se.14, Se.29 Q	1.25
National Lead, pfd. A	New York	142⅞	142	142	Au.31, Se.15 Q	1.75
National Lead, pfd. B	New York	119½	118	118	Oc. 19, No.1 Q	1.50
St. Joseph Lead	New York	46¾	44¾	46	Se.8, De.20 QX	0.75
ZINC						
Am. Z. L. & S	New York	57	48⅝	49½	May, 1917	1.00
Am. Z. L. & S. pfd	New York	117⅞	102⅞	109½	Nov., 1920	1.50
Butte C. & Z	New York	9	8	8⅛	De., 1926	0.50
Butte & Superior	New York	11⅞	10½	11⅛	Se.14,Se.29 Q	0.50
Callahan Zn-Ld	New York	3¾	3¼	3⅜	De., 1920	0.50
Consol.Lead&Zinc 'A'	St. Louis	11½	11	11	Je.25, Jl.1 Q	0.25
Eagle-Picher	Cincinnati	19⅞	19	19½	No.15, De.1 Q	0.40
Eagle-Picher pfd	Cincinnati	...	...	100	July 15 Q	1.50
Evans-Wallower	N. Y. Curb	7½	6½	6½		
New Jersey Zn	N. Y. Curb	228	226	228	Oc.20, Nov. 10 Q	2.00
Treadwell-Yukon	Toronto	10.50	9.90	10.50		
United Zinc	N. Y. Curb	...	...	*70		
Yellow Pine	Los Angeles	*25	*25	*25	Dec., 1925 QX	0.04
GOLD						
Alaska Juneau	New York	8	4	7½		
Ankerite	Toronto	...	...	*28		
Barry-Hollinger	Toronto	*43	*37½	*39		
Central Manitoba	Toronto	*86	*80	*80		
Cresson Consol. G	N. Y. Curb	*76	*68	*68	Oct. 15, Q	0.02
Dome Mines	New York	9	8½	9	Se.29, Oc.20 Q	0.25
Gold Hill	Toronto	*9	*8	*8½		
Golden Cycle	Colo.Springs	†1.63	†1.61½	...	My. 31, Je.10 Q	0.04
Hollinger Consol	Toronto	10.25	7.50	10.00	Oc 17, No. 3 FW	0.05
Homestake Mining	New York	76	75	75½	Oc.20, Oc. 25 M	0.50
Kirkland Lake	Toronto	1.31	1.15	1.23		
Lake Shore	Toronto	20.00	19.05	19.15	Se.1, Se.15 XQ	0.20
McIntyre Porcupine	New York	20	19½	20	No.1, De.1 Q	0.25
Portland	Colo.Springs	†*17	†*15	....	Ap., 1927	0.02
Rand Mines	New York	...	...	40	Au.21-28 Am.Sh	1.52
Sylvanite	Toronto	2.55	2.25	2.40		
Teck-Hughes	Toronto	8.80	8.25	8.40	Oc.17, No.1	0.15
Tom Reed	Los Angeles	*58	*50	*50	Dec., 1926	0.02
Tough-Oakes	Toronto	*20	*12	*13		
Vipond Cons	Toronto	*59	*52	*58	April, 1927	0.03
Wright-Hargreaves	Toronto	2.70	2.45	2.51	Oc.16, No.1 Q	0.02½
GOLD AND SILVER						
Carnegie Metals	N. Y. Curb	25⅛	22	24½		
Con. Cortez	N. Y. Curb	...	...	*19		
Dolores Esperanza	N. Y. Curb	1	*96	1	July, 1923	0.05
N.Y. Hond's Rosario	N. Y. Curb	...	...	16	Oc.17, Oc.27 QX	0.50
Premier Gold	N. Y. Curb	2¼	2⅛	2⅛	Se.14, Oc.4 Q	0.06
Tonopah Belmont	N. Y. Curb	*75	*75	*75	Oc., 1925	0.05
Tonopah Extension	N. Y. Curb	*7	*7	*7	Ap., 1925	0.05
Tonopah Mining	N. Y. Curb	3⅞	3½	3½	Se 29,Oc.20 SA	0.07½
West End Consol	N. Y. Curb	...	...	*37	Mar., 1923	0.05
Yukon Gold	Boston Curb	*76	*70	*76	June, 1918	0.02
SILVER						
Beaver Consol	Toronto	*69	*69	*69	May, 1920	0.03
Castle-Trethewey	Toronto	*38½	*37½	*38		
Coniagas	Toronto	...	....	2.75	May, 1924	0.12½
Keeley	Toronto	*44	*42	*42	Mr.1, Mr.15 SA	0.04
Lorrain Trout Lake	Toronto	....	....	*50	July, 1925	0.05
Mining Corp. Can	Toronto	3.20	2.95	3.00	My.20, Je.13 SA	0.125
Nipissing	N. Y. Curb	3½	2¾	3½	Se.29, Oc.20 Q	0.07½

Stock	Exch.	High	Low	Last		Last Div.
SILVER-LEAD						
Ahumada	New York	3⅜	3⅛	3⅛	Ap., 1927	0.12½
Bingham Mines	Boston	48	47½	48	Se.20, Oc.5 Q	0.50
Bunker Hill & Sullivan	N. Y. Curb	122¾	117	118	Se.29, Oc. 4 MX	0.75
Cardiff M. & M	Salt Lake	*34	*31	*34	Feb. 5, 1927	0.10
Chief Consol	Salt Lake	3.95	3.80	3.90	Ja.10, Fe.1 K	0.10
Consti'nMng.&Mill'g	Spokane	*39	*34	*39		
Erupcion	Boston Curb	*25	*25	*25	Ja., 1928 Q	0.07½
Eureka Lily	Salt Lake	1.67½	1.60	1.60		
Federal M. & S	New York	161½	161	161	Je., 1927	10.00
Federal M. & S. pfd	New York	101¼	100	101½	Au. 24, Se. 15 Q	1.75
Golconda	Spokane	*76	*75	*75		
Hecla Mining	N. Y. Curb	15¼	14⅞	15	Au.15, Se. 1 Q	0.15
Highland-Surprise	Spokane	*12⅜	*12	*12		
Iron King Mining	Salt Lake	*93	*89	*90		
Keystone Mining	Salt Lake	†*35	†*25		Fe., 1926	0.07½
Lucky Jim	Spokane	*25	*23½	*24½		
Lucky Tiger-Com	Kansas City	†6.85	†6.55	...	Oc.4, Oc.20 M	0.05
Mammoth Mining	Salt Lake	†1.45	†1.30	....	De., 1926	0.25
North Lily	Salt Lake	7.90	7.65	7.70	Oct., 20 I	0.20
Park Utah	New York	11	10⅛	10⅜	Se.,11, Oc.1 Q	0.20
Plutus Mining	Salt Lake	†2.00	†1.60	....	Ap.10, Ap.16 Q	0.10
Rico-Argentine	Salt Lake	*49	*48½	*49	June 15 Q	0.03
Sherman Lead	Spokane	*22	*20	*21		
Silver King Coal	Salt Lake	13.50	13.25	13.37½	Se.20, Oc.1 Q	0.25
Silversmith	Spokane	*11	*10	*10	Oct., 1926 Q	0.02
Strattons Mines	Spokane	1.37	1.25	1.25		
Sunshine M. Co	Spokane	1.32	1.30	1.32	June 20, K	0.02
Tamarack-Custer	Spokane	*41½	*41	*41	Sept., 1924	0.25
Tintic Standard	Salt Lake	14.00	13.62½	13.75	Se.19, Se.29 QX	0.30
Utah-Apex	Boston	4	3½	4	Jl.14, Au.1 K	0.25
IRON						
Bethlehem Steel	New York	72½	67⅜	67⅞	Jl., 1924	1.25
Cleveland-Cliffs Iron	Cleveland	1.44	1.19½	1.44	Oc.15, Oc.25 Q	1.00
Colorado F & I, pfd	New York	70	64⅞	66	Au.10, Au.25 Q	2.00
Gt. North'n Iron Ore	New York	30⅞	24½	29⅞	Ap. 9, Ap. 30 K	0.75
Inland Steel	New York	74½	70⅝	71½	Au. 15, Se.1 Q	0.62½
Republic I. & S	New York	85¾	81½	81⅞	Au. 14, Se. 1 Q	1.00
Republic I. & S. pfd	New York	108⅜	108¼	108⅜	Se. 15, Oc. 1 Q	1.75
Sloss-Sheffield S. & I	New York	...	...	120	Se.10, Se.20 Q	1.50
Sloss-Shef. S.&I. pfd	New York	...	...	106	Se. 20, Oc. 1 Q	1.75
U. S. Steel	New York	165⅜	161⅞	162	Au.30, Se.29 Q	1.75
U. S. Steel, pfd	New York	141⅞	141¼	141⅜	Au. 6, Au. 30 Q	1.75
Virginia I. C. & C	New York	....	....	25½	Jan., 1924	1.50
Virginia I.C.&C. pfd	New York	....	....	50	Je. 16, Jl. 2 SA	2.50
DIAMONDS, PLATINUM, ALUMINUM, VANADIUM, TIN						
De Beers Consol	New York	24¼	24¼	24½	Ju.16, Ju.26 K	0.97
So. Am. G. & P	New York	...	...	3⅜		
Alum. Co. of Amer	N. Y. Curb	140½	138	139⅜		
Alum. Co. of Amer. pf.	N. Y. Curb	107¾	107¼	107¾	Se. 15, Oc. 1 Q	1.75
Vanadium Corp	New York	82¾	78½	79¼	No. 1, No. 15 Q	0.75
Patino M. & E	New York	35⅝	33⅜	34½	April, 1928	4s.
ASBESTOS						
Asbestos Corp	Montreal	29¼	26	27	Jan., 1926	1.50
Asbestos Corp. pfd	Montreal	87	86	86½	Se.29, Oc.15 Q	1.75
SULPHUR						
Freeport Texas	New York	56	48¼	49½	Oc.15, No.1 QX	1.25
Texas Gulf	New York	74⅜	70	72½	Se. 1½, Se 15 Q	1.00
MINING, SMELTING, REFINING AND GENERAL						
Amer. Metal	New York	52	49	49¾	Au. 21, Se 1 Q	0.75
Amer. Metal, pfd. 6%	New York	111½	111½	111½	Au.15, Se.1 Q	1.50
Amer. Sm. & Ref	New York	270⅞	254½	267½	Oc.11, No.1 Q	2.00
Amer. Sm. & Ref. pfd	New York	137	136½	137	No.2, De. 1 Q	1.75
Consol. M. & S	Montreal	279	263	274	Je.30, Jl.16 SAX	6.25
Newmont Mining	N. Y. Curb	183¾	168¼	180	Se.28, Oc.15 Q	1.00
U. S. Sm. R. & M	New York	54¾	51⅜	52⅞	Oc.5, Oc. 15 Q	0.87½
U.S. Sm. R.&M. pfd	New York	53½	53	53	Oc. 5, Oc. 15 Q	0.87½

*Cents per share. †Bid or asked. Q, Quarterly. A, Annual. SA, Semi-annually. M, Monthly. FW, four weeks. K, irregular. I, Initial. X, Extra. The first date given is that of the closing of the books; the second that of the payment of the dividend.

Boston quotations courtesy Boston Stock Exchange; Toronto quotations those of the Standard Stock Exchange of Toronto, by courtesy of Arthur E. Moysey & Co.; Spokane, Pohlman Investment Co.; Salt Lake, J. A. Hogle & Co.; Colorado Springs, Colo., Henry Sachs.

LONDON QUOTATIONS—WEEK ENDED October 9, 1928

Name	High	Low	Last	Date		Last Div. Amount
Alaska Mexican ($5)	35/6	35/—	35/—			
Alaska Treadwell ($25)	120/6	120/—	120/—	Nov.,	1926	4 (d)
Aramayo Mines (25 frs.)	62/3	58/9	60/—	Aug,	1928	5 p.c. (†)
Burma Corpn. (10 rupees)	15/1½	14/6	14/10½	Aug.,	1928	6 annas*
Bwana M'Kubwa (5s)	7/6	7/—	7/4½			
Camp Bird (2s)	4/6	4/—	4/—	April,	1928	16⅔ p.c.
El Oro (£1)	4/10½	4/6	4/9	Nov.,	1924	2½ p.c.*
Frontino & Bolivia (£1)	11/3	10/—	10/—	July	1928	3½ p.c.
Mexican Corpn. (£1)	11/—	10/—	11/—			
Mexico Mines of El Oro (£1)	30/—	23/9	30/—	Dec.,	1926	3½ p.c.*
Mond Nickel	141/3	131/3	136/3	Aug.,	1928	20 p.c.
N'Changa Copper Mining	19/10½	18/3	19/6			
Oroville Dredging (£1)	3/9	3/1½	3/6	Dec.,	1923	3½ p.c.
Rhodesian Congo Border (£1)	33/6	28/9	30/—			
St. John del Rey (£1)	13/7½	12/—	12/9	April,	1928	7½ p.c.
San Francisco Mines (10s)	28/9	28/3	28/6	July	1928	12½ p.c.
Santa Gertrudis (£1)	15/6	14/—	15/3	July	1928	7½ p.c.
Selukwe (2s. 6d.)	9/1½	8/3	9/—	April,	1917	6¾ p.c.
S. Amer. Copper (2s.)	2/7½	2/1½	2/6	Nov.,	1917	75 p.c.
Tanganyika (£1)	62/6	58/9	60/—	July	1928	5 p.c.
Union Miniere du Haut-Katanga (Brussels)	11,000	10,000	10,950	July,	1928	182.60 (b)

*Free of British income tax. †Swiss francs and plus 15 p. c. bonus. ‡Belgian frs. and free of taxation.